GCMAS 2025

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June 17-21, 2025

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GCMAS 2025

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Local Conference Chair

Kirsten Tulchin-Francis, PhD

Program Chair

R. Tyler Richardson, PhD

Scientific Committee

Ross Chafetz, PT, DPT, PhD, MPH
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Sahar Hassani, MS
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SPECIAL THANKS

A special thanks to the following people from Nationwide Children's Hospital

Tammy Hudson
Tracy Sferra
Kelly Hallberg
Jennifer Denny
Ruth Mauk

Columbus, OH

PRESIDENTIAL WELCOME

Colleagues,

Welcome to the 30th Annual meeting of the Gait and Clinical Movement Analysis Society in Columbus, Ohio. Thank you to our Conference Chair, Kirsten Tulchin-Francis, and Program Chair, Tyler Richardson, who have led the planning for what promises to be another wonderful meeting! I hope each of you will take a moment this week to express your thanks to our planning team.

We look forward to bringing the next generation of physicians, therapists, biomechanists, and engineers to the meeting, and I hope all of you have the opportunity to meet and welcome them. We are making an effort to expand our conference offerings and support for students and young professionals. Tuesday and Wednesday we provide an introductory gait course by some of the leaders in the field. To support networking we have a student/young professional mixer with our board of directors and an active mentor/mentee program. Please encourage your students and other young professionals to become a part of our organization, and if you are an experienced member of our organization, please consider becoming a mentor.

A special welcome to our exhibitor attendees. Their support is essential to our society. Please take the time to spend time with our vendors to explore the latest technology and products during our welcome reception or breaks in the program. Several user group meetings will be hosted on Thursday after the day's conference activities.
Whether this is your first GCMAS conference or you are a long-time member, I hope you feel welcome and encouraged to take part in Q&As after the podium presentations, or to follow up with speakers informally after a session.

I am proud of the progress that has been made in our field by our board of directors and council chairs. We will share updates at our business lunch on Friday and there is a breakfast session on Thursday to meet with council chairs. Please remember that our Society is built on the engagement and commitment of its members who volunteer time, energy, and service to one of the Councils. If you would like to contribute, talk to a Board member—there are many opportunities!

Thank you for coming and enjoy Columbus!

Chris Church, MPT
Chris.Church@nemours.org
2023-2025 GCMAS President

SPECIAL THANKS TO OUR REVIEWERS!!

Alison Hanson
Braden Romer
Charalambos C Charalambos
Christine Doss Esper
Corey Joseph
Eva Ciccodicola
Jason Long
Jessica Lewis
Jose Salazar-Torres
Joseph Krzak
Karen M. Kruger
Kevin Dibbern
Kirsten Tulchin-Francis
Krisanne Chapin
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Richa Tripathi
Riley Horn
Robert Courter
Seth Donahue
Stephen Glass
Subham Badhyal
Tasos Karakostas
R. Tyler Richardson
Vishnu Deep Chandran
Whitney Wolf
M. Wade Shrader
Zahra Bassiri

GCMAS 2025

CONFERENCE CHAIR WELCOME

On behalf of Nationwide Children's Hospital, I am delighted to welcome you to Columbus for the 2025 GCMAS Meeting. During your time with us, I hope you have a chance to explore Columbus and the amazing things our city has to offer. Our Welcome Reception will be held Wednesday evening at our conference hotel, *The Graduate*, located in the Short North Arts District. Throughout the week I hope you will be able to enjoy the many restaurants and shopping up and down High Street. The GCMAS banquet will be held at Pins Mechanical – a fun-filled social with duckpin bowling, arcades, BBQ, and more.

The scientific meetings will be held on the main campus of Nationwide Children's Hospital in our Conference Center. The conference would not be possible without the amazing work of our program committee and Board of Directors. I would like to thank the GCMAS Board of Directors, especially Dr. Chris Church, for their dedication and hard work in planning this meeting. It was an absolute pleasure working with Tyler Richardson as this year's program chair. He has put together some great new sessions! I would also like to thank the NCH conference staff, particularly Tammy Hudson and Tracy Sferra for their hard work and diligence in the details! Dr Ross Chafetz has led the charge to expand our GCMAS Basics of Gait Analysis pre-course to two full days, with new hands-on sessions. Finally, I'd like to thank all of our sponsors for their continued support of GCMAS. We hope that our open floorplan will encourage all attendees to engage with each of the exhibitors throughout the meeting.

Welcome to Columbus and enjoy GCMAS 2025!

Kirsten Tulchin-Francis, PhD
2025 GCMAS Conference Chair

A MESSAGE FROM OUR PROGRAM CHAIR

Welcome to the 2025 Gait and Clinical Movement Analysis Society meeting! Our society is a diverse and multi-disciplinary group of physicians, allied health professionals, engineers, and biomechanists. As such, the research and work conducted by our society members exemplifies the power of collaboration between clinicians and scientists to have a substantial impact toward improving functional outcomes and quality of life for individuals with movement disorders.

This year's program demonstrates that very collaborative spirit and impact. The 2025 program includes 51 podium presentations across nine content areas and 26 poster presentations. We are excited to feature a Top Abstracts of GCMAS 2025 podium session containing top-scoring abstracts that will be eligible for this year's Best Paper Award as well as a podium session highlighting Student Thesis Talks.

We are very pleased to host two breakfast sessions and two tutorials that offer innovative perspectives on gait analysis and a networking opportunity to get involved with the GCMAS councils. We are also excited to offer a two-day educational conference pre-course on clinical gait analysis that features both clinical and technical tracks.

Finally, we are especially thrilled to welcome two fantastic keynote speakers, Dr. Scott Delp from Stanford University, and Dr. Robert Kay from Children's Hospital Los Angeles, who will share their expert perspectives and insights on clinical motion analysis.

We would like to thank all the abstract reviewers, session moderators, the GCMAS leadership board, and the Nationwide Children's conference planning team for helping to make this year's conference possible. I would also like to express my deep personal gratitude to our Conference Chair, Kirsten Tulchin-Francis, for being so gracious in sharing her wealth of knowledge with me as I learned the ropes. It has been a great honor to serve as Program Chair and to help organize a compelling program for this year's conference. I am grateful for the trust that you all have placed in me to carry out this important service.

Thank you for coming and enjoy the 2025 GCMAS conference in Columbus!

Tyler Richardson, PhD
GCMAS 2025 Program Chair

Columbus, OH

GENERAL MEETING INFORMATION

LEARNING OBJECTIVES

1. Describe & evaluate technologies for measuring kinematic, kinetic, EMG data, in-shoe pressure profiles, and other biomechanical variables of interest.
2. Interpret & critically compare kinematic, kinetic, and EMG data from patients with movement disorders, both before and after treatment.
3. Summarize current "best practices" for treating gait abnormalities in persons with cerebral palsy, stroke, and other movement disorders and musculoskeletal disorders.

REGISTRATION

Wednesday, June 18 * Mixer & Welcome Reception	5:00 PM – 7:00 PM
Thursday, June 19	7:00 AM – 4:00 PM
Friday, June 20	7:00 AM – 4:00 PM

PRESENTATION UPLOAD

Podium presentations should have been uploaded through the Cloud CME system prior to the conference. No laptop connections will be allowed at the podium. Please find the AV table at the rear of the Allen Auditorium for any questions or updates to your slides.

POSTER PRESENTERS

All posters should be hung by 9:00AM on Thursday. Posters should be removed at the end of the day on Friday. Posters that remain after the day's final session will be discarded.

Group A Thursday, June 19	9:45 AM – 10:30 AM
Group B Friday, June 20	9:45 AM – 10:30 AM

WELCOME RECEPTION

Join us at our host hotel, The Graduate, for networking and fellowship on Wednesday evening at our welcome reception. Drink tickets will be available.

Wednesday, June 18	6:00 PM – 8:00 PM

CMLA LUNCHEON

The Commission for Motion Lab Accreditation will host an informational luncheon on Thursday. Box lunch provided

Thursday, June 19	11:45 AM – 12:45 PM

BUSINESS MEETING

The annual GCMAS Member Business Meeting will be held on Friday. Please join your GCMAS Board of Directors to hear the 'State of the Society'. Box lunch provided.

Friday, June 20	12:00 PM – 1:00 PM

GAIT LAB TOUR

Tours of the Nationwide Children's Hospital Honda Center for Gait Analysis and Mobility Enhancement are available immediately following the end of the conference.. A late shuttle will be available after the tour.

Thursday, June 19	5:15 PM -6:00 PM

SHUTTLES

Transportation will be provided between The Graduate Hotel and Nationwide Children's Hospital each day.

	Departs Hotel	Departs NCH
Thursday	6:40 AM 7:40 AM**	5:30 PM ** 6:15 PM
Friday	6:40 AM 7:40 AM **	5:30 PM **
Saturday	7:40 AM **	12:15 PM

*** Multiple shuttles available*

ACCREDITATION

This activity has been approved for 27.75 *AMA/PRA Category 1 CME credits*.

2-Day Pre-course: 11.75 credits
3-Day Conference: 16.00 credits

In support of improving patient care, this activity has been planned and implemented by Nationwide Children's Hospital and the Gait and Clinical Movement Analysis Society (GCMAS). Nationwide Children's Hospital is jointly accredited by the Accreditation Council for Continuing Medical Education (ACCME), the Accreditation Council for Pharmacy Education (ACPE), and the American Nurses Credentialing Center (ANCC), to provide continuing education for the healthcare team.

Nationwide Children's Hospital designates this live activity for a maximum of 27.75 *AMA PRA Category 1 Credit(s)*™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.

Texas Physical Therapy Board: This activity has been submitted for review. States with reciprocity with Texas Physical Therapy Association: AL, AK, AZ, CT, DE, GA, HI, ID, IN, IA, KS, KY, LA, ME, MA, MI, MN, MI, MS, NE, NH, NC, ND, OR, PA, RI, SC, SD, TN, UT, VT, VA, WA, WI, WY.

GCMAS 2025

PRE-COURSE

Basics of Gait Analysis & Interpretation

Tuesday, June 17: 9:00 AM – 4:30 PM

Wednesday, June 18: 9:00 AM – 4:30PM

Course Faculty

Co-Directors: Kirsten Tulchin-Francis, PhD
Co-Director: Ross Chafetz, PT, DPT, PhD, MPH, MS
Amy Barbuto, PT
Eric Dugan, PhD
Carl Gelfius, MD
Karen Kruger, PhD
Joseph Krzak, PT, PhD
Mark McMulkin, PhD
Sylvia Ounpuu, MS
Prabhav Saraswat, PhD
M. Wade Shrader, MD
Amy Shuckra, PT
Sean Tabaie, MD
Sean Waldon, MD

Course Description

The purpose of this course is to provide anyone working in a clinical gait lab basic background education necessary for becoming competent in data analysis/interpretation and/or the technical modeling used for gait evaluation. On Tuesday June 17th, there are two tracks – clinical and technical. The Basics of Clinical Gait Analysis interpretation will focus on data interpretation and clinical recommendations and is designed for all gait lab staff, including clinicians, engineers, kinesiologists etc. The Basics of Technical Gait analysis, also on Tuesday June 17th, will focus on the technical aspect of gait analysis for those interested in modeling and data analytics. On Wednesday, June 18th, the two groups will join for an all-day, physician-led, case review session.

Target Audience

Physicians, physical therapists, engineers, kinesiologists, physician assistants, nurse practitioners, etc. The target audience for this course is anyone who may be ordering, conducting, or interpreting a gait analysis evaluation.

Course Objectives

1. Demonstrate understanding of the basic typical gait.
2. Demonstrate understanding of kinematic, Kinetic and EMG graphs.
3. Demonstrates understanding of using kinematics, kinetics and EMG to identify gait pathologies.

Optional Evening Pre-Course Session

Tuesday June 17th 5:30 PM – 7:30 PM

There will be an optional hands-on course activity on Tuesday evening.

- The clinical course participants will be reviewing basic motion lab physical exam. Please bring loose fitting clothing and a copy of Shriner's Children's Physical Exam – available on the members-only section of the GCMAS website.
- The technical course participants will be doing live equipment QA demonstrations.
- There will be a 60min break at 4:30 PM-5:30. Participants may go on a NCH-staff lead outside walk/tour of NCH to stretch their legs followed by provided dinner prior to the start of the evening session.

Columbus, OH

KEYNOTE SPEAKERS

Thursday, June 19: 12:45 PM – 2:30 PM

"Past, Present, and Future of Clinical Gait Analysis"

Scott Delp, PhD

James H. Clark Professor of Bioengineering, Mechanical Engineering, and Orthopaedic Surgery
Director, Wu Tsai Human Performance Alliance at Stanford
Chair, National Leadership Council, Wu Tsai Human Performance Alliance
Director, Restore Center
Director, Mobilize Center
Co-Creator, SimTK

Scott L. Delp, Ph.D., is the James H. Clark Professor of Bioengineering, Mechanical Engineering, and Orthopaedic Surgery at Stanford University. He is the Founding Chairman of the Department of Bioengineering at Stanford, and Director of the Wu Tsai Human Performance Alliance at Stanford, a university-wide research initiative focused on discovering biological principles to optimize human performance and catalyze innovations in human health for all. Dr. Delp is also the Director of the Restore Center, an NIH national center focused on measuring real world rehabilitation outcomes, and Director of the Mobilize Center, a NIH National Center of Excellence focused on Big Data and Mobile Health. Scott is focused on developing technologies to advance movement science and human health. Software tools developed in his lab, including OpenSim and Simtk.org, have become the basis of an international collaboration involving thousands of students and scientists who exchange simulations of human movement. Prior to joining the faculty at Stanford, Delp was on the faculty at Northwestern University and the Rehabilitation Institute of Chicago. He has published over 325 research articles in the field of biomechanics and has published a textbook from MIT Press entitled Biomechanics of Movement: The Science of Sports, Robotics, and Rehabilitation. Professor Delp has co-founded six health technology companies and is a member of the U.S. National Academy of Engineering.

Friday, June 20: 2:30 – 4:15PM

"Walk This Way: Lessons Learned from the Gait Lab"

Robert Kay, MD

Chief, Division of Orthopedic Surgery
Director, Jackie and Gene Autry Orthopedic Center
Director, Neuromuscular Program
Associates Chair in Orthopedics
Children's Hospital Los Angeles
Clinical Scholar and Professor of Orthopedic Surgery, Keck School of Medicine of USC

Robert Kay, MD, serves as Division Chief of Orthopedic Surgery and Medical Director of the Jackie and Gene Autry Orthopedic Center. In these roles, he provides administrative and clinical leadership that includes overseeing the strategic planning, recruitment and programmatic development for the Orthopedic Center's clinical, research and educational programs focused on bone and soft tissue tumors; childhood hip disorders; hand and upper extremity conditions; neuromuscular conditions; scoliosis and spinal deformity; and sports medicine and other orthopedic trauma injuries.

Dr. Kay earned his undergraduate degree from Harvard College and medical degree from the Johns Hopkins University School of Medicine. He completed his residency at the University of California, Los Angeles, as well as a pediatric orthopedic fellowship at Children's Healthcare of Atlanta - Scottish Rite Hospital.

Dr. Kay began at CHLA in 1997 and joined the faculty of the Keck School of Medicine of USC, where he now is a Professor of Orthopedic Surgery. Prior to being named Division Chief, Dr. Kay served as Vice Chief of the Children's Orthopaedic Center from 2009 to 2021. He has also served as Chief of the Medical Staff at CHLA from 2009 to 2011, and as Medical Director of the John C. Wilson Jr. Motion and Sports Analysis Laboratory since 1997. Under his leadership, the laboratory has become internationally renowned and remains one of only 21 fully accredited motion analysis laboratories in the United States. The lab, which has been accredited by the Commission for Motion Laboratory Accreditation (CMLA) four times, is the second lab in history to receive CMLA full accreditation with no deficiencies.

Dr. Kay has published more than 140 peer-reviewed articles and 25 book chapters. He is active in the American Academy of Orthopaedic Surgeons, Pediatric Orthopaedic Society of North America, American Academy for Cerebral Palsy and Developmental Medicine, and the Gait and Clinical Movement Analysis Society. He serves on the Editorial Board for the Journal of Pediatric Orthopaedics and the Board of Directors for the Committee for Motion Laboratory Accreditation.

GCMAS 2025

TUTORIAL A

Thursday, June 19: 10:30AM – 11:45AM, Allen Auditorium

Moving Towards the Future – The Role of Mocap, Wearables and AI in the Evaluation and Assessment of Individuals with Movement Pathology

Presenters

Nathan Edwards, PhD, TSAC-F & Kirsten Tulchin-Francis, PhD

Purpose

This instructional course provides a complex overview of various data acquisition methods to assess human motion. This course aims to equip healthcare professionals with the knowledge to distinguish which methodologies are most effective for their practices, ensuring the best possible outcomes and long-term health in individuals with movement pathology.

Target Audience

Engineers, kinesiologists, therapists, researchers, and clinicians interested in expanding the reach of gait and motion analysis

Summary

These include 2D single and multi-camera apps for smart phones and tablets, three-dimensional marker-based and markerless motion analysis, and a wide variety of wearable sensors, both research-grade and consumer-based. Methods will be reviewed including ease of use, platforms available (cloud, etc.), type of data collected, accuracy and pros/cons across the spectrum of young athlete populations.

Many of the analysis packages within these motion capture tools use artificial intelligence and machine learning applied within computer vision to identify movement patterns. Artificial intelligence is quickly developing into a variety of tools that can be used to improve the efficiency of data collection and analysis. This course aims to review AI integration into movement analysis and function with a particular focus on its ability to aid in developing patient-specific, precision healthcare delivery.

Agenda

5 mins	Introduction
40 mins	Motion capture methods • Review the current state, supporting literature, and pros & cons of each method of motion analysis - Observation - 2D Photo/Video - 3D Instrumented Motion Analysis - Markerless Mocap - Inertial Measurement Units
15 mins	Role of AI, computer vision, machine learning in motion analysis • Extended discussion on role of computer vision methods in single, two, and multi-camera markerless systems • Examine current efforts to utilize AI and machine learning to standardize gait interpretation
15 mins	Questions

Learning Objectives

By the end of this tutorial, participants will be able to:

- Understand and distinguish the variation between different technology driven data acquisitions – from 2D video capture apps and 3D motion capture (markers and markerless) to wearable sensor systems.
- Discuss appropriate patient populations, data collection settings, and pros/cons for each of the data acquisition methods.
- Discuss the role that artificial intelligence (AI) plays, in conjunction with these methods, in developing precision healthcare planning

Columbus, OH

TUTORIAL B

Thursday, June 19: 10:30 AM – 12:00 PM, 2nd Floor Room 2.6

Measuring Walking Activity Outside of the Gait Analysis Laboratory

Presenters

Chris Church, MPT, Faithe R. Kalisperis, DPT, Nancy Lennon, PT, MS, DPT, Stephanie Butler, DPT, M. Wade Shrader, MD

Purpose

The purpose of this course is to describe the feasibility, challenges and latest evidence for measuring walking activity (WA) in people with cerebral palsy (CP), with a focus on clinical implementation.

Target Audience/Prerequisite Knowledge

Rehabilitation professionals and orthopedic surgeons and who care for ambulatory youth and adults with CP. Basic knowledge of cerebral palsy, walking activity, and gait analysis.

Summary

The digital world allows easy tracking of health metrics such as sleep, heart rate, step counts, and diet. Awareness can lead to improvement of these metrics and better overall health. WA is a simple metric measured by daily step counts that reflects health-related fitness and participation in mobility-based life habits. Children with CP have lower levels of WA, less participation, and higher amounts of sedentary time compared to peers, putting them at risk for poor physical and mental health. Our gait analysis team adopted the practice of measuring WA as part of clinical testing over a decade ago. This tutorial will describe the challenges we encountered, examine our clinical experiences, review our research findings, and share our best advice with those interested in measuring WA in clinical practice. We will review data from our lab and compare evidence from around the world. We will describe our measurement protocol and its psychometrics and will examine factors found to influence WA. We will engage the audience with interactive case review that highlights our learning objectives.

Presentation Format

5 mins	**Introduction, Overview of Course Objectives**
15 mins	**Review of Literature on Walking Activity in Youth with CP** • Describe the relationship of WA to health and quality of life • Review literature of WA across childhood for typical and children with CP • Examine factors that influence WA in youth with CP • Examine associations of WA with functional outcomes and quality of life measures
10 mins	**Review of Literature on Walking Activity in Adults with CP and stroke** • Review literature of WA in adults with CP • Review evidence for improving WA in adults with stroke
10 mins	**Measuring Walking Activity in Clinical Practice** • Review clinical protocols for data capture • Describe data processing and management • Explain interpretation/documentation/dissemination of WA data among surgeons, families, and therapists • Review reimbursement for clinical WA testing
15 mins	**Walking Activity Outcomes in Surgical Care of Youth with CP** • Review our process of setting goals and expectations for surgery • Describe the evidence on recovery of WA after orthopedic surgery • Examine factors associated with recovery of WA post-operatively
20 mins	**Interactive Case Examples** • How does WA data and sharing among surgeons/therapists/families increase WA? • How does baseline WA data influence the surgical / rehab plan? • What are the expectations for recovery from orthopedic surgery? • Can awareness of WA change life habits/participation?

Learning Objectives

By the end of this tutorial, participants will be able to:

1. Explain evidenced-based protocols for the measurement of walking activity
2. Describe the role of walking activity measurement in the care of people with CP
3. Understand the factors that influence walking activity for people with CP
4. Overcome the challenges of adopting walking activity measures in clinical practice

GCMAS 2025

BREAKFAST SESSIONS

Thursday, June 19 - 7:00 – 8:00 AM

GCMAS Council Networking & Information

Presenters

Awards Council:	Kevin Dibbern, PhD	Reimbursement Council:	Christine Doss Esper MD
Communication Council:	Braden Romer, PhD	Research Council:	Adam Fullenkamp, PhD
Education Council:	Ann Flanagan, PT	Standards Council:	Eric Dugan, PhD
Membership Council:	Karen Kruger, PhD		

Summary

GCMAS has several councils that each serve to further the mission of the organization and maintain the society in several important ways. Each of these councils is comprised of current GCMAS members and welcomes new participation from members who feel compelled to serve the society. The chair of each council will provide a brief (2-3 minutes) overview of their responsibilities and current activities of their council followed by instructions on how members can get involved with their council. Attendees will be encouraged to rotate around the session to learn about multiple councils while offering an opportunity to network with other GCMAS members.

Objectives

1. Learn about the core responsibilities of each GCMAS council
2. Understand how to become involved with each GCMAS council
3. Offer networking opportunities between GCMAS members

Friday, June 20 7:00 AM– 8:00 AM

Evidence Based Gait Analysis Interpretation Tools (EB-GAIT): Treatment Recommendation and Outcome Prediction Models to Support Decision-Making in Clinical Gait Analysis

Presenter

Andrew G. Georgiadis, MD

Summary

Clinical gait analysis (CGA) currently relies on subjective clinician experience and judgment, which may contribute to the modest, stagnant, and unpredictable gait outcomes observed after surgical treatment for gait impairments. We introduce a novel framework: Evidence-Based Gait Analysis Interpretation Tools (EB-GAIT). This approach leverages machine learning to support treatment decisions. EB-GAIT consists of two key components: (1) treatment recommendation models, which are propensity models that estimate the probability of specific surgeries based on historical standard-of-practice (SOP), and (2) treatment outcome models, which predict changes in patient characteristics following treatment or natural history.[1] Currently, those models are presented in an interactive format for interrogation by the clinician.

EB-GAIT represents a significant step toward precision medicine in CGA, offering a promising tool to enhance treatment outcomes and patient care. This may be achieved by focusing clinician attention on data relevant to decision-making and outcome, and providing honest estimates of uncertainty.

Columbus, OH

SCIENTIFIC SESSIONS Thursday, June 19

8:15 AM – 9:45AM Cerebral Palsy & Gait

Moderators: *Kristan Pierz, MD & Tishya Wren, PhD*

8:15	**The Effect of Immediate Weightbearing After Planovalgus Foot Reconstruction in Ambulatory Children with Cerebral Palsy** *Chris Church, Hannah Scott, Madison Lennon, Jose Salazar-Torres, Christina Herrero, Rachel Lenhart, Hannah Popper, Abigail Helms, Nancy Lennon, **M. Wade Shrader,** Jason J. Howard, Arianna Trionfo*
8:30	**Hip Displacement in Spastic Hemiplegia: Increased Risk with Hip Internal Rotation and Adduction Irrespective of Sagittal Gait Pattern** *Zhe Yuan; Alexander Aretakis; Chris Church, **M. Wade Shrader,** Freeman Miller, Anuj Gupta, Arianna Trionfo, Jason J. Howard*
8:45	**Inpatient Rehabilitation after Multi-Level Surgery in Youth with Cerebral Palsy: Acute and 1 Year Mobility Outcomes** ***Stephanie Butler,** Brittany Virgil, Katie Bushong, Arianna Trionfo, Jose Salazar-Torres, Chris Church, Nancy Lennon*
9:00	**A Comparison of Different Insertion Approaches for Anterior Distal Femoral Hemiepiphysiodesis on Sagittal Knee Kinematics: A Case Series** *Jessica L. Stockhausen, Kellen T. Krajewski, Amanda L. Vinson, Lucas Moore, Scott Miller, James J. Carollo, Mariano Garay, Radomir Dimovski, Sayan De, **Jason Rhodes***
9:15	**The Association Between Anterior Pelvic Tilt and Back Pain in Adults with Cerebral Palsy** *Chris Church, **Madison Lennon,** Victoria Hinchberger, Jose Salazar-Torres, Nancy Lennon, M. Wade Shrader, Freeman Miller, Jason J. Howard*
9:30	**3D-Instrumented Gait Analysis for Surgical and Rehabilitative Treatment Decisions in Children with Cerebral Palsy: Results from a 2024 Clinical Practice Guideline** *Mark L McMulkin, Joseph J Krzak, **Rebecca A States**, Yasser Salem, Ellen M Godwin, Sandra L Kaplan*

2:15 PM – 3:45 PM Top Abstracts of GCMAS of 2025

Moderators: *Scott Delp, PhD & Wendy Pierce, MD*

2:15	**Relationship between Upper Extremity Reachable Workspace Measures and Patient-Reported Outcomes in Brachial Plexus Birth Injury and Cerebral Palsy** ***R. Tyler Richardson**, Stephanie A. Russo, Ross S. Chafetz, Spencer Warshauer, Natalie Williams, Dan A. Zlotolow, Scott H. Kozin*
2:30	**Feasibility of Markerless Motion Capture for Assessing Gait in Diverse Clinical, Pediatric Populations** *Robert Courter, Spencer Warshauer, Seth Donahue, Jing Feng, Sean Waldron, **Ross Chafetz***
2:45	**Assessing Balance and Stability in Individuals with Prune Belly Syndrome** ***Mallory Rowan**, Jessica Lewis, Matthew Parrett, Nathalia G. Amado, Linda A. Baker, Ajit Chaudhari, Kirsten Tulchin-Francis*

3:00 **Can Single-Leg Crossover Drop Landing Mechanics Predict a Second ACL Injury?**
Lauren A. Luginsland, Nathan D. Schilaty, Gregory D. Myer, Kim D Barber Foss, Aaron J. Krych, Nathaniel A. Bates

3:15 ***Biomechanical and Functional Outcomes of High and Low Burden Multi-Level Surgery in Youth with Cerebral Palsy***
Tori Hinchberger, Brittany Virgil, Chris Church, Anjana Bhat, Jose Salazar-Torres, John Henley, Wade Shrader, Freeman Miller, Jason Howard, Nancy Lennon

3:30 **Investigation of the Head-Shake Sensory Organization Test (HS-SOT) in the Yaw Plane**
Neha Kapoor, Kiara Barrett, Megan Cotterman, Kristinn Heinrichs

4:00 PM – 5:15 PM Data Analysis & Methods

Moderators: *Tasos Karakostas, MPT, PhD & Peter M. Quesada, PhD*

4:00 **Using Radiographs to Evaluate Different Regression Equations for the Hip Joint Center in Children with Cerebral Palsy**
Reiko Hara, Tishya Wren

4:15 **The Role of AI in Gait Analysis: Comparing Human and AI Performance in Selecting Representative Gait Trials**
Jessica Lewis, Mallory Rowan, Matthew Parrett, Kirsten Tulchin-Francis

4:30 **Predicting Gait Kinematics in Youth with Cerebral Palsy using Clinically-Informed Machine Learning Algorithms**
Daniel Wagner, Nancy Lennon, Chris Church, Jose Salazar-Torres, C Nataraj, Freeman Miller, David Cereceda, Jason J Howard.

4:45 **Comparison of Markerless and Marker-Based Motion Analysis in Children with Cerebral Palsy Wearing Hinged Ankle-Foot Orthoses**
Riley Horn, John D. Collins, Heather Waters, Christine Amacker, Martins Amaechi, Rachel M. Thompson, Patrick Curran, Henry G. Chambers

5:00 **Explainable Deep Clustering of Full Time Series Instrumented Gait Data from Children with Unilateral Cerebral Palsy**
Troy Krupinski, Renugopal Sivaprakasam, Lakhisha Balaji, Joe Krzak, Adam Graf, Anita Bagley, Jeremy Bauer, Jon Davids, Susan Sienko, Haluk Altiok, Mark Albert, Karen Kruger, Kevin Dibbern

SCIENTIFIC SESSIONS Friday, June 20

8:15 AM – 9:45 AM Pathological Motion & Gait

Moderators: *Robert Kay, MD & Sylvia Õunpuu, MSc*

8:15 **Not All AFO's Are Created Equal for Walking Faster After Stroke**
Walter B. Weiss, Valerie J. Eberly, Sara J. Mulroy, Jeffery W. Rankin

8:30 **Transverse Plane Kinematics Frequently Change for Children and Adolescents with Idiopathic In-toeing or Out-toeing Between Walking and Running**
Mark L. McMulkin, Mitchell Maniatopoulos, Ted Sousa

8:45 **Using Motion Capture to Assess Function in Patients with Facioscapulohumeral Muscular Dystrophy**
Jessica Lewis, Matthew Parrett, Mallory Rowan, Kirsten Tulchin-Francis

9:00 **Selective Motor Control Correlates with Gait Function in Patients with Hereditary Spastic Paraplegia**
Lizabeth Bunkell, Kelly Jeans, Lane Wimberly

9:15 **Error Based Biofeedback for Gait Retraining From a Single Wearable Sensor**
Seth Donahue, Zachary Hoegberg, Matthew J. Major

9:30 **Temporal-Spatial Differences Between Discrete and Continuous Walking Trials**
Jason T. Long, Ashley M. Moulder

10:30 AM – 12:00 PM Trunk & Upper Extremity

Moderators: *Stephanie Russo, MD, PhD & M. Wade Shrader, MD*

10:30 **Reachable Workspace After Mastectomy: A Case Series**
Lauren N. Lottier, Stephanie A. Russo, R. Tyler Richardson

10:45 **Seated vs. Standing Spine Kinematics: The Importance of Establishing Normative Data for Non-Ambulatory Populations**
Jessica Lewis, Mallory Rowan, Matthew Parrett, Kirsten Tulchin-Francis

11:00 **Validity of Markerless Motion Capture Detecting Spine Range of Motion in Scoliosis**
Spencer Warshauer, Robert Courter, Jing Feng, Joshua Pahys, Sean Waldron, Ross Chafetz

11:15 **Age-Related Changes in Spinal Range of Motion: A Motion Capture Analysis**
Lawrence Saltis, Mallory Rowan, Matthew Parrett, Jessica Lewis, Kirsten Tulchin-Francis

11:30 **Biomechanical Analysis of Trunk and Spinal Kinematics in Idiopathic Scoliosis: A Review of Current Efforts in Three-Dimensional Motion Capture**
Matthew Parrett, Lincoln Glaros, Jessica Lewis, Mallory Rowan, Kirsten Tulchin-Francis

11:45 **Assessing the Potential for Abnormal Gait Patterns in Athletes with Spondylolysis**
Steve Wilson, Mallory Rowan, Ivan Slyepkan, Matthew Parrett, Jessica Lewis, Kirsten Tulchin-Francis

GCMAS 2025

2:30 PM – 3:45 PM Sports & Performance

Moderators: *Eric Dugan, PhD & Jason Rhodes, MD*

2:30	**The Association Between Strength Changes and Kinematic Changes in High School Cross Country Runners Following a Competition Season** *Jason T. Long, Jeffery A. Taylor-Haas, Ashley M. Moulder*
2:45	**Assessing Trunk Kinematics in Athletes With Pathology: A Multi-Segment Model Approach** *Mallory Rowan, Lincoln Glaros, Ivan Slyepkan, Matthew Parrett, Jessica Lewis, Reid Chambers, Kirsten Tulchin-Francis*
3:00	**Hemophilia Severity Impacts Range of Motion During Simulated Sports Activities** *Danielle Siegel, Caden Robertson, Dianne Thornhill, Joanna Roybal, Niamh Mah, Sharon Funk, Marilyn Manco-Johnson, James Carollo, Brecca Gaffney, Beth Warren*
3:15	**Return-To-Sport Motion Capture Testing After Posterior Spinal Fusion: Comparing Trunk Metrics Pre- Versus Post-Operation** *Josh Pahys, Maura Eveld, Ross Chafetz, Susan Sienko, Patrick Do, Spencer Warshauer, Robert Courter, Emily Nice, David Louie, Chinmay Paranjape, Jeremy Bauer*
3:30	**Lower Extremity Coordination Variability Reduces During an Incremental Cycling Test** *Braden Romer, M. Tysinger, S Chretien, S Piombino, D Derrenbacher, C Benoit, C Carriker*

4:00 PM – 5:15 PM Student Thesis Talks

Moderators: *Kevin Dibbern, PhD & Suzann Donovan, BS*

4:00	**Impact of Adjusting Theia3D User Settings on Lower Limb Kinematic Outcomes During Overground Walking in Typically Developing and Children with Cerebral Palsy** *Jutharat Poomulna, David Kingston*
4:15	**A People-First Gait Analysis Device: Bringing Sensor-Based Gait Assessment into Everyday Care** *Sameeksha Naik, Aaryan Nagpal, Fae Azhari*
4:30	**Comparing Spatiotemporal Characteristics of Stepping-in-Place and Overground Walking in Healthy Adults** *Malicki Diallo, Shawanee' Patrick, Trevor Evans, Ajit Chaudhari*
4:45	**"Row to Grow": Measuring Kinematic Changes in Gait and Rowing in Adolescents with Cerebral Palsy after Participation in a Rowing Program** *Ali Hawkins, K. Davies, C. Pollock, Tim Bhatnagar, Lise Leveille*
5:00	**The Effect of Aquatic Environment and Speed on the Co-Contraction of Lower Limbs Muscles in Cerebral Palsy Children** *Colina Matthews, Joseph Harrington, Vivek Dutt, Brian Knarr, David Kingston*

Columbus, OH

SCIENTIFIC SESSIONS Saturday, June 21

8:15 AM – 9:45 AM Balance/Posture & Quality, Service, Delivery

Moderators: *Stephen Glass, PhD & Joseph J. Krzak, PT, PhD*

8:15	**Revisited: GCMAS Podium/Poster Publication Rates - Did the COVID-19 Pandemic Impact Our Scientific Dissemination?** ***Zachary Beneteau***, *Kirsten Tulchin-Francis*
8:30	**Assessing Quality and Readability of Clinical Gait/Motion Analysis Laboratories in the US: Are Families Getting the Right Information?** *Kirsten Tulchin-Francis,* ***Laura Bates****, Matthew Parrett, Mallory Rowan, Jessica Lewis, Sean Tabaie*
8:45	**The Effects of Subsensory Electrical Noise Stimulation on the Compensatory Reactions During Support Surface Perturbations** ***Zahra Bassiri****, Oluwasegun Akinniyi, Nathan Humphrey, Dario Martelli*
9:00	***Balance on Single and Infinite Axes Passively Unstable Surfaces with Intact and Blurred Acuity*** ***Peter M. Quesada****, Drake R. Crosby*
9:15	**Evaluating Postural Control in Prune Belly Syndrome with the Timed Up & Go Test** ***Mallory Rowan****, Jessica Lewis, Matthew Parrett, Linda A. Baker, Ajit Chaudhari, Kirsten Tulchin-Francis*
9:30	**Neck and Shoulder Kinematics During Seated Computer Work in Women with Chronic Neck Pain** ***Whitney L. Wolff****, Joshua M. Leonardis*

10:00 AM – 11:15 AM Foot & Ankle

Moderators: *Howard J. Hillstrom, PhD & Sean Tabaie, MD, MBA*

10:00	**Comparison of Static Alignment and Segmental Foot Kinematics** ***Karen M. Kruger****, Joseph J. Krzak, Adam Graf, Angela Caudill, Ann Flanagan, Nancy Scullion, Bryana Vasquez, Ross S. Chafetz*
10:15	**The Ten-Year Outcome of the Ponseti Method in Children With Idiopathic Clubfoot and Arthrogryposis** *Chris Church, Nicole Wang;* ***Stephanie Butler****, Jose Salazar-Torres, John Henley, Freeman Miller, Nancy Carlin, Maureen Donohoe, Louise Reid Nichols*
10:30	**First Ray Mobility Measurement: Reliability and Utility in Healthy and Pathological Feet** ***Minah Waraich****, Howard J Hillstrom, Robert Turner, Silvia Zanini, Kaitlyn Sheehy, Bret Drakos, Jinsup Song, Mark Drakos, Scott Ellis, Matthew Conti, Jonathan T Deland III, Holly Ann Johnson, Constantine Demetracopoulos, Emily Teehan, Rajshree Hillstrom*
10:45	**Objective Documentation of the Natural Progression of Gait Decline in Charcot-Marie-Tooth Type 1A: A Case Study** ***Sylvia Õunpuu****, Tishya Wren, Jennifer Rodriguez-MacClintic,Gyula Acsadi, Kristan Pierz*
11:00	**Understanding Peak Dorsiflexion in Terminal Stance in Youth With Charcot-Marie-Tooth Disease** ***Sylvia Õunpuu****, Kristan Pierz, Jennifer Rodriguez-MacClintic, Lauren Bargmann, Zahra Bassiri, Emmanuelle Tiongson, Gyula Acsadi, Tishya Wren*

GCMAS 2025

POSTER SESSION A Thursday, June 19

9:45 – 10:30 AM

1A	**Effects of Orientation, Blurred Acuity and Cognitive Task on Balance on a Single Axis Passively Unstable Surface** ***Peter M. Quesada***, *Brandon R. Bays, Thomas E. Ray*
2A	**Can Comparing Sibling Data Provide Insights into Progression of Gait Decline in CMT 1A? Clinical Case Study** ***Sylvia Óunpuu,*** *Tishya Wren, Jennifer Rodriguez-MacClintic, Gyula Acsadi, Kristan Pierz*
3A	**Automated Gait Classification: Comparison of Automated Algorithms to Expert Classification** ***Karen M. Kruger***, *Ross S. Chafetz, Joseph J. Krzak, Susan E. Sienko, Jeremy P. Bauer*
4A	**Relationship Between Pelvic Tilt Measured in Radiographs and Gait Analysis** *Zhenkun Gu,* ***Vishnu D. Chandran***, *Giulia Beltrame, Silvia Zanini, Bridget Assip, Jennifer Jezequel, Fernando Q. Gonzalez, Howard Hillstorm, David Scher, Paulo Selber*
5A	**Pre-Post Surgery Outcomes of a Youth with Spastic Diplegic Cerebral Palsy** ***Brianna Troksa***, *Jennifer Winters, Mohan Belthur, Subham Badhyal*
6A	**Gait Deviations and Compensatory Mechanisms following Limb Salvage: A Pediatric Case Study** ***Daryn Strub***, *Mallory Rowan, Jessica Lewis, Matthew Parrett, Kim Bjorklund, Thomas Scharschmidt, Kirsten Tulchin-Francis*
7A	**Variation in Activity Level Measurement Using Wrist- and Ankle-Based Activity Monitors: Preliminary Findings from a Pilot Cohort** ***Jason T. Long***, *Emma Austing, Jillian Kreimer, Ashley M. Moulder, Amy F. Bailes*
8A	**Utility of Gait Analysis in Treatment of Pseudoachondroplasia: A Case study** ***Alison Hanson***, *John Livingstone, Jonas Owen, Tishya Wren*
9A	**Which Activity to Use to Identify Optimal Knee Axis for Sport Movements: Walks or Squats?** ***Farah T. Azim***, *Ali Hawkins, Tim Bhatnagar*
10A	**A Comparison of Plug in Gait and CGM2 1.0** ***Corey Joseph***, *Anna Murphy, Nikos Darras*
11A	**Ability of Children with Persistent Idiopathic Toe Walking and a Moderate Calf Contracture to Achieve a First Rocker in Gait** ***Mark L. McMulkin***, *Bruce A. MacWilliams, Susan E. Sienko, Jon Davids, Paige Lemhouse, Jeremy P. Bauer*
12A	**Long-Term Changes in Functional and Ambulatory Status of Patients with Myelomeningocele** ***Tasos Karakostas***, *Diego Restrepo-Tous, Ana-Marie Rojas, Jill Larson, Vineeta Swaroop, Luciano Dias*

POSTER SESSION B Friday, June 20

9:45 – 10:30 AM

1B	**Spine Motion Deviations in Spondylolysis Patients** *Ivan Slyepkan, Mallory Rowan, Jessica Lewis, Matthew Parrett, Kirsten Tulchin-Francis*
2B	**Motor Equivalence Analysis of a Novel Mini-Squat Task from Varying Initial Stance Configurations** *Stephen Glass, Beau Houchins, Nathan Iskowitz, Breanna Mouer, Andrew Tompkins*
3B	**A Cluster Analysis on Trunk and Pelvic Kinematics in Children with Diplegic Cerebral Palsy** *Vishnu D. Chandran, Olivia C. Tracey, Akshitha Adhiyaman, Silvia Zanini, Bridget Assip, Jennifer Jezequel, Dara Jones, Howard Hillstorm, David M Scher, Paulo RP Selber*
4B	**Effect of Talocalcaneal Coalitions on Foot and Ankle Kinematics in Adolescents** *Victoria Blackwood, Kelly Jeans, Rusty Hartman, Jacob Zide, Anthony Riccio*
5B	**Concurrent Validity of Modern Motion Analysis Tools for Reachable Workspace Assessment** *Ross Chafetz, Shaun Q. Y. Tan, Yishan Zhong, Benoit Marteau, Andrew Hornback, Wenqi Shi, Spencer Warshauer, Robert Courter, Lauren Lottiers, Stephanie Russo, Robert T. Richardson, May D. Wang, Seth Donahue*
6B	**Is Gait Symmetrical in Patients with Hereditary Spastic Paraplegia?** *Lizabeth Bunkell, Kelly Jeans, Lane Wimberly*
7B	**Overlooking Knee Height Asymmetry: Is There Functional Consequences?** *Aurélie Grandchamp, Jean-Francois Girouard, Julie Basset, Mathieu Lalumière, Reggie C. Hamdy, Louis-Nicolas Veilleux*
8B	**Pre-Post Surgery Outcomes of a Patient with Hurler Syndrome** *Brianna Troksa, Jennifer Winters, Mohan Belthur, Subham Badhyal*
9B	**The Clinical Utility of Knee Walking in Identifying Compensatory Movements** *Matthew Parrett, Jessica Lewis, Mallory Rowan, Kirsten Tulchin-Francis*
10B	**Effects of Twister Cables on the Malalignment of the Lower Extremity in Children with Gait Disorder** *Harshvardhan Bollepalli, Stacy Stibb, Xue-Cheng Liu*
11B	**Internal hip rotation and swing phase knee flexion in typical adolescent gait: A case-control pilot study** *Krisanne Chapin, P. Dalloo*

GCMAS 2025

YOUNG PROFESSIONAL & STUDENT ACTIVITIES

WELCOME MIXER – On Wednesday evening, prior to the welcome reception, please join our young professional and student attendees in the at the Graduate Hotel, Level 2. Our Board of Directors will be in attendance, offering a unique opportunity for young professional and student attends to socialize and mingle.

MENTORSHIP MEET-UP – GCMAS has an excellent mentorship program where our young professionals, students and trainees are matched with a senior researcher or clinician. Matched pairs can meet up in the **Exhibitor Hall** over lunch. Seating will also be available on the 2nd floor in the Spark Space, for those looking for a quieter area to speak.

STUDENT THESIS SESSION – On Friday afternoon, selected students have an opportunity to present their research through a special Student Thesis Session in the Allen Auditorium. Come support the future of our society.

Welcome Mixer	The Graduate Hotel, Level 2	Wednesday, June 18	5:00 PM – 6:00 PM
Mentorship Meet-up	NCH, 2nd Floor- Spark Space	Thursday, June 19	11:45 AM – 12:45 PM
Student Thesis Session	NCH, Allen Auditorium	Friday, June 20	4:00 PM – 5:15 PM

NETWORKING BANQUET

Friday, June 21: 6:30 PM – 8:30 PM

Join us for an evening of networking and mingling at PINS Mechanical. A fun-filled destination featuring duckpin bowling, dozens of classic pinball machines & many more 'old school' entertainment options along with high-quality cocktails and crafts beers. Food provided by City Barbeque.

PINS MECHANICAL COMPANY

City BARBEQUE

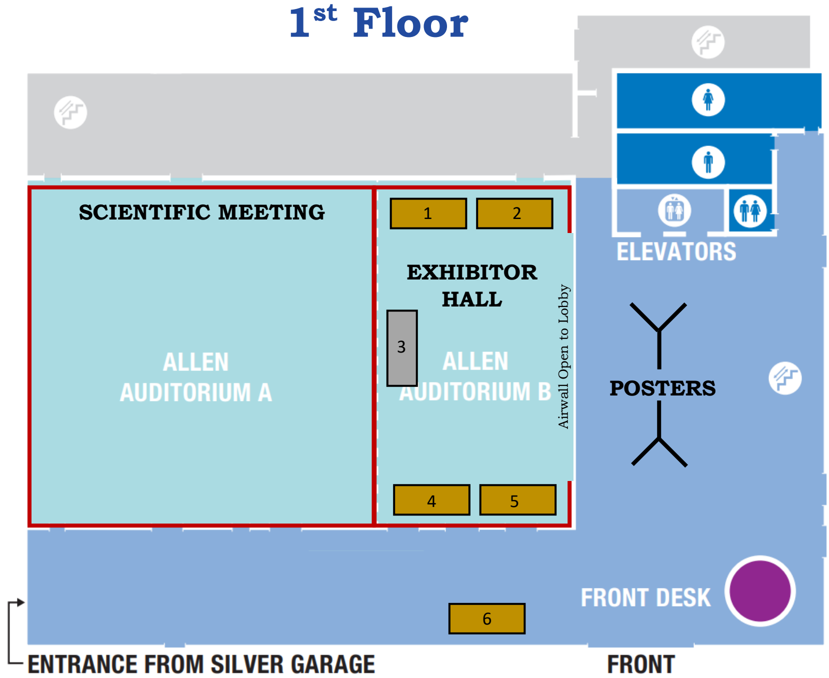
SAVE THE DATE!

Columbus, OH

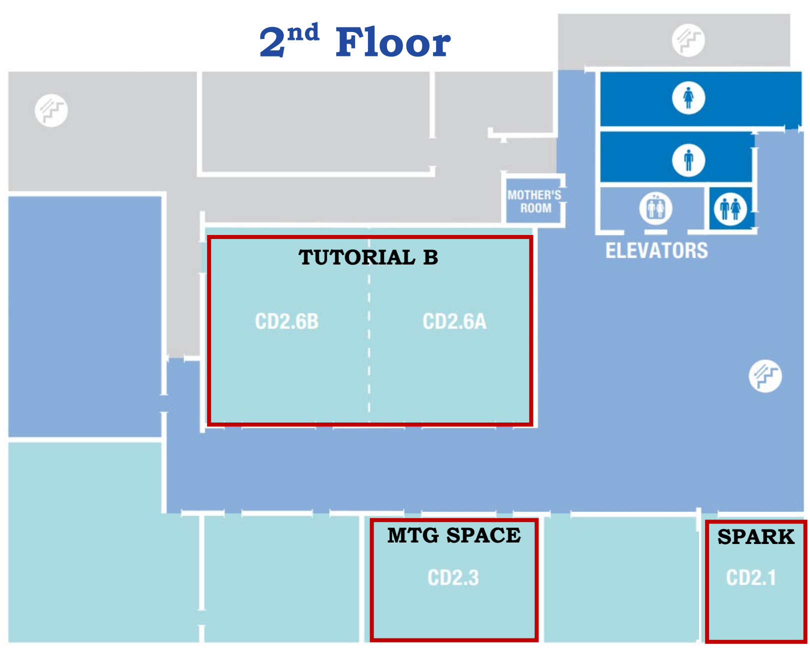
EXHIBITOR & CONFERENCE FLOORPLAN

1	VICON	2	MOVESHELF	3	QUALISYS
4	BTS Bioengineering	5	AMTI FORCE AND MOTION	6	DELSYS

1st Floor



2nd Floor



PROGRAM AT GLANCE

	Thursday June 19	Friday June 20	Saturday June 21
7:00	**Breakfast Session** **GCMAS Councils Networking & Info** *7:00 AM – 8:00 AM*	**Breakfast Session** **Evidence-Based Gait Analysis Interpretation Tool (EB-GAIT)** *7:00 AM – 8:00 AM*	
7:15			
7:30			
7:45			
8:00	**Welcome** *8:00 AM – 8:15 AM*	**Welcome** *8:00 AM – 8:15 AM*	**Welcome** *8:00 AM – 8;15 AM*
8:15	**Session 1** **Cerebral Palsy & Gait** *8:15 AM – 9:45 AM*	**Session 4** **Pathological Motion & Gait** *8:15 AM – 9:45 AM*	**Session 8** **Balance/Posture & Quality, Service, Delivery** *8:15 AM – 9:45 AM*
8:30			
8:45			
9:00			
9:15			
9:30			
9:45	**Poster Session A** **Vendor Break** *9:45 AM – 10:30 AM* *Lobby/Exhibitor Hall*	**Poster Session B** **Vendor Break** *9:45 AM – 10:30 AM* *Lobby/Exhibitor Hall*	**Break** (9:45 AM – 10:00 AM)
10:00			**Session 9** **Foot & Ankle** *10:00 AM – 11:15 AM*
10:15			
10:30	**Tutorial A** **AI & Mocap for Gait Analysis** *10:30 –11:45 AM* **Allen Auditorium** **Tutorial B** **Measuring Walking Activity Outside the Lab** *10:30 – 11:45 AM* **2nd Floor: 2.6**	**Session 5** **Trunk & Upper Extremity** *10:30 AM – 12:00 PM*	
10:45			
11:00			
11:15			**Break** (11:15 AM – 11:30 AM)
11:30			**Closing & Awards** *11:30 AM – 12:-00 PM*
11:45	**CMLA Lunch** *11:45 AM – 12:45 PM* **Mentorship Meet-up** *11:45 AM– 12:45 PM*		
12:00		**Business Lunch** *12:00 PM – 1:00 PM*	**All meetings held in Allen Auditorium, unless otherwise noted**
12:15			
12:30			
12:45	**Keynote Address** **Scott Delp, PhD** *12:45 PM – 2:00 PM*		
1:00		**Keynote Address** **Robert Kay, MD** *1:00 PM – 2:15 PM*	
1:15			
1:30			
1:45			
2:00	**Break** (2:00 PM – 2:15 PM)		
2:15	**Session 2** **Top Abstracts of GCMAS 2025** *2:15 PM – 3:45 PM*	**Break** (2:15 PM – 2:30 PM)	
2:30		**Session 6** **Sports & Performance** *2:30 PM – 3:45 PM*	
2:45			
3:00			
3:15			
3:30			
3:45	**Break** (3:45 PM – 4:00 PM)	**Break** (2:15 PM – 2:30 PM)	
4:00	**Session 3** **Data Analysis & Methods** *4:00 PM – 5:15 PM*	**Session 7** **Student Thesis Talks** *4:00 PM – 5:15 PM*	
4:15			
4:30			
4:45			
5:00			
5:15			
5:30			
5:45			
6:00+	**User Group Meetings/ Dinner on your own**	**Banquet @ Pins Mechanical Co** 6:30 PM – 8:30 PM	

HAVE A QUESTION FOR A SPEAKER?

Microphones will be located in the center aisle. Please wait until the end of the presentation to approach the microphone. State your name and affiliation.

If you would prefer to submit a question online, please scan the QR code, select the session and presenter.

THE EFFECT OF IMMEDIATE WEIGHTBEARING AFTER PLANOVALGUS FOOT RECONSTRUCTION IN AMBULATORY CHILDREN WITH CEREBRAL PALSY

Chris Church, MPT; Hannah Scott; Madison Lennon, BS; Jose Salazar-Torres, PhD; Christina Herrero, MD; Rachel Lenhart, MD, PhD; Hannah Popper, DO; Abigail Helms, PA; Nancy Lennon, DPT; M. Wade Shrader, MD; Jason J. Howard, MD; Arianna Trionfo, MD
Nemours Children's Hospital, Alfred I. duPont Campus, Wilmington, DE
E-mail: cchurch@nemours.org

INTRODUCTION: Planovalgus (PV) foot deformity is one of the most common foot deformities in children with CP. Orthopedic surgery is widely established as an effective treatment for deformity correction though there is clinical variation in post-op therapy protocols [1]. Immediate weightbearing (WB) after PV foot correction could accelerate recovery but concern for post-op complications causes reluctance. The aims of this study are to determine the prevalence of complications and associated risk factors after PV foot surgery in ambulatory children with cerebral palsy (CP).

CLINICAL SIGNIFICANCE: This evaluation of WB and non-WB (NWB) protocols in children with CP can be used to guide post-operative treatment and enhance patient care.

METHODS: This IRB-approved retrospective cohort study included ambulatory children (GMFCS I-III) with CP and PV foot deformity who underwent reconstructive surgery and pre (within 18 months) and post-op (1-3 years) gait analyses. Children were excluded if they did not have post-operative X-ray images available. At gait analyses, coronal plane pressure index values were calculated using differences in pressure between medial and lateral parts of the foot. Chart reviews were completed to identify comorbidities (seizures; bone health issues), surgical procedure, level of surgical burden, casting duration, presence of bracing, and weightbearing status following surgery. Complications were defined in three timeframes: (1) short-term, within 6 months of surgery, by radiograph review for nonunion, hardware failure, or infection requiring return to surgery, (2) mid-term, at 1-3 years, by pedobarographic assessment, and (3) long-term, > 3 years, by recurrence requiring surgical revision. Fisher exact tests compared the prevalence of complications between immediate WB and NWB groups. Regression analysis evaluated the relationship between complications and child, surgical, and post-operative factors.

RESULTS: A total of 135 children with CP; GMFCS I (12%), II (58%), III (30%) met inclusion criteria. 140 surgical events were completed on 224 feet at age 12.7 ± 2.8 years. Following surgery, 84% of children followed an immediate WB protocol, and 16% were NWB for the first six weeks. The prevalence of short-term complications between the WB and NWB groups was no different (nonunion/hardware failure/infection, WB 3%/1%/0%; NWB, 0%/3%/0%; $p>0.9$). There were no between group differences in mid-term correction status (under-corrected/corrected/over-corrected, WB 31%/45%/24%; NWB, 32%/54%/14%; $p>0.9$). The prevalence of long-term recurrence necessitating surgery was not significantly different (WB/NWB, 3%/11%; 8.5±2.8 years post-op; $p>0.9$). Regression analysis demonstrated WB status was not a significant predictor of correction status or long-term recurrence requiring revision ($p>0.05$).

Table 1. Follow-up of complications in weightbearing (WB) and non-weightbearing (NWB) patients.

Follow-up	Outcome	WB (%)	NWB (%)	p-value Fisher Exact Test
Short-term *(≤ 6 Mos)*	Nonunion	3.0	0.0	0.99
	Hardware Failure	1.0	2.7	0.99
	Infection Requiring Acute Return to OR	0.0	0.0	0.99
Mid-term *(1-3 yrs)*	Undercorrected	31.0	32.4	0.99
	Corrected	45.0	54.0	
	Overcorrected	24.0	13.5	
Long-term *(8.5±2.8 yrs)*	Recurrence	3.0	10.8	0.99

DISCUSSION: In this population, the distribution of short-term complications (nonunion, hardware failure, infection requiring acute return to OR) in both WB and NWB groups was rare (<=3%). No significant difference in distribution of short-term complications between WB and NWB groups were found demonstrating early WB did not present higher risk of short-term complications in our sample. In midterm follow up (1-3 years post operatively), correction of the foot to within 1 deviation of typical average was observed in about half of the children (45.0% WB, 54.0% NWB). As there were no significant difference in correction across WB and NWB, no added risk is demonstrated with the WB protocol following PV reconstruction. While there was no difference between groups, pre-operative CPPI was found to be significantly predictive of correction status, where a more valgus foot (increased CPPI) is more likely to be under corrected. Results demonstrate risks regarding correction status are not related to WB protocol, but severity of foot deformity itself. Recurrence of PV foot deformity requiring additional surgery was low in both WB (3.0%) and NWB (10.8%) groups within 8.5 +- 2.7 years of surgery. No significant difference in long term-recurrence with no significant risk factors suggests that early WB does not present higher risk of long-term recurrence.

Complication rates were low after planovalgus foot correction surgery in ambulatory children with CP. There were no significant differences in complications, clinical outcomes, or need for surgical revision between groups who followed immediate WB vs. NWB post-op protocols. As there are no significant risks, early WB following PV surgery should be encouraged in children with CP. Early WB, standing, and walking may prevent disuse muscle weakness and promote faster recovery of gross motor mobility, enhancing patient care. Future studies should examine the impact of early WB on recovery time and long-term functional outcomes.

REFERENCES:

1. Schafer et al. (2007) Effects of early weight bearing on the functional recovery of ambulatory children with Cerebral Palsy 3-year follow up

DISCLOSURE STATEMENT: We have no conflicts to disclose.

Hip Displacement in Spastic Hemiplegia: Increased Risk with Hip Internal Rotation and Adduction Irrespective of Sagittal Gait Pattern

Zhe Yuan, Alexander Aretakis, Chris Church, M. Wade Shrader MD, Freeman Miller, Anuj Gupta, Arianna Trionfo, Jason J. Howard
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INTRODUCTION

Hip displacement (HD) is a common problem for children with cerebral palsy (CP), typically less prevalent for patients with hemiplegia [1]. According to the most commonly used classification for hemiplegia, patients with a Winter-Gage-Hicks (WGH) Type IV gait pattern (Figure) are thought to be at increased risk of HD [2], but the true prevalence was unknown. Gait-related factors, including excessive hip internal rotation or adduction, may increase this risk. The aim of the study was to analyze the rates of HD according to WGH classification and to identify risk factors to inform surveillance protocols.

CLINICAL SIGNIFICANCE

Defining the prevalence of hip dysplasia will determine the need for hip surveillance protocols in ambulatory children with hemiplegic CP.

METHODS

This IRB-approved retrospective study was performed at a tertiary-level children's hospital with an accredited gait laboratory. Those with hemiplegic CP, at least one instrumented gait analysis, hip surveillance x-ray(s), and minimum 2-year follow-up were included. The primary outcome was the presence of an "unsuccessful hip", defined as a migration percentage (MP) ≥30% and/or undergoing reconstructive osteotomies for HD. Secondary outcomes included: WGH Type, previous hip surgery (for gait rather than HD), gender, scoliosis, epilepsy, ventriculoperitoneal shunt, G-tube, hip internal rotation and/or flexion, adduction, and abduction moment identified on instrumented 3D gait analysis (3DGA). Chi-square and logistic regression analysis assessed the impact of patient characteristics, WGH classification, and gait parameters on the risk of an unsuccessful hip outcome.

RESULTS

One hundred forty-four patients were included (39.6% female), classified as GMFCS I (45.1%) or II (54.9%), with a mean follow-up of 9.6±4.6 years. The number of hip surveillance x-rays per patient was 5.7±4.1. For the entire cohort, 17 patients (11.8%) had an unsuccessful hip outcome (age 11.6±3.6 years) by final follow-up. Stratified by WGH Type, unsuccessful hip outcome rates were I: 9.5% (2/21), II: 9.4% (6/64), III: 6.7% (2/30), and IV: 24.1% (7/29). Age at onset of an unsuccessful hip outcome was not different between WGH Types (p=0.8). Only gait-related risk factors were found to be significant: hip flexion (p=0.03), hip internal rotation (p=0.004), and hip adduction (p=0.006) at initial contact were associated with an unsuccessful hip (univariate). Multivariate analysis identified hip internal rotation (OR:4.7, CI:1.2-18.1, p=0.02) and hip adduction (OR:5.2, CI:1.2-22.1, p=0.02) as significant risk factors for an unsuccessful hip outcome.

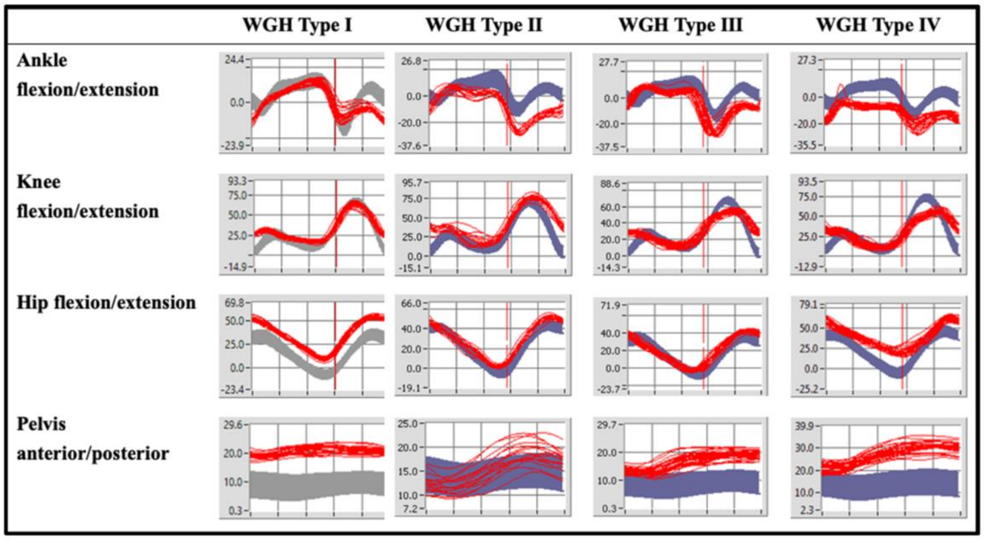

Figure. Representative sagittal kinematic gait patterns depicting the Winter-Gage-Hicks (WGH) classification: WGH I=Foot drop without ankle equinus, knee and hip range of motion ok; WGH II=Ankle equinus, knee and hip range of motion ok; WGH III=Ankle equinus, stiff knee, hip range of motion ok; WGH IV=WGH III plus decreased hip range of motion. Adapted from Winters TF Jr, Gage JR, Hicks R. Gait patterns in spastic hemiplegia in children and young adults. J Bone Joint Surg Am. 1987;69:437-441.

DISCUSSION

The rates of HD in spastic hemiplegia were higher than expected for all WGH Types, particularly IV (24%). Notably, the rates for Types I-III (~7-9%) were surprising, previously thought to have negligible risk of HD. Regardless of WGH Type, a sagittal plane classification, patients with increased hip internal rotation (transverse plane) and adduction (coronal plane) were at risk. A high index of suspicion and regular hip surveillance x-rays are required for patients with these risk factors, starting in the pre-adolescent phase.

REFERENCES

1. Hägglund G. et al. (2005) J. Bone Jt. Surg. Ser. B. 87(1):95-101.
2. Soo B, et al. (2006). J Bone Joint Surg Am. 88(1):121-129.

DISCLOSURE STATEMENT

Authors have no conflicts to disclose.

INPATIENT REHABILITATION AFTER MULTI-LEVEL SURGERY IN YOUTH WITH CEREBRAL PALSY: ACUTE AND 1-YEAR MOBILITY OUTCOMES

Stephanie Butler, DPT; Brittany Virgil, DPT; Katie Bushong, Arianna Trionfo, MD;

Jose Salazar, PhD; Chris Church, MPT; Nancy Lennon, DPT, MS, PT.

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INTRODUCTION

Multi-level surgery (MLS) is standard of care for correcting musculoskeletal deformities in ambulatory youth with cerebral palsy (CP).[1] Acute functional decline after MLS has been described and inpatient rehabilitation (IPR) intends to improve basic mobility function for a smooth transition to home. While the immediate benefits of IPR seem clear, its effect on the broader goal of improving long-term mobility should be examined. The aim of this project is to describe IPR for youth with CP after MLS and examine its association with acute and 1-year recovery of mobility function.

CLINICAL SIGNIFICANCE

Clarifying the impact of IPR is important to guide post-operative treatment and planning to optimize the surgical outcomes for children with CP.

METHODS

This IRB approved retrospective study examined youth with CP age 7-20 years, Gross Motor Function Classification System (GMFCS) levels II and III who had high burden[2] (≥ 2 osteotomies) MLS between 2017-21 with instrumented gait analysis (IGA) pre- and post-op. Exclusion criteria were < 2 osteotomies or simultaneous upper limb surgery. Acute mobility change was evaluated with The Functional Independence Measure for Children (WeeFIM), mobility subtotal, administered during IPR. One-year mobility change was evaluated by (1) The Pediatric Outcomes Data Collection Instrument (PODCI), Transfer and Basic Mobility (TBM) subscale, (2) the Gross Motor Function Measure-Dimension D (GMFM-D), and (3) the Gait Deviation Index (GDI). Cognitive impairment was identified using the WeeFIM. Descriptive factors were summarized with median and interquartile range (IQR). Mobility outcomes were analyzed with Wilcoxson-tests or T-tests as appropriate. Regression analysis was used to identify factors associated with acute and one-year mobility change.

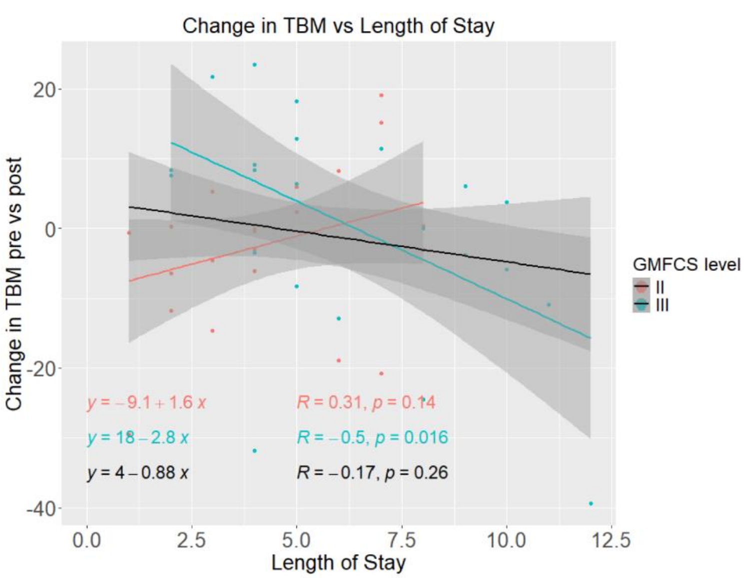
RESULTS

58 patients met inclusion criteria, average age 13.5 yrs. (+/- 3.1), 60% male, GMFCS levels II (53%), III (47%). Median (IQR) number of osteotomies was 3 (2-4). 19% of patients did not have and 81% had IPR, with median (IQR) length of stay (LOS) of 5 weeks (4-7). Youth at GMFCS Level III had significantly longer LOS compared to GMFCS II ($p<0.05$). There were significant gains in WeeFIM mobility during IPR ($p<.001$). Lower WeeFIM cognitive scores and lower pre-op GMFM-D scores were associated with less gains in mobility acutely ($p<0.001$ and

p<0.05). There were significant improvements in GDI (p<0.01), but no significant change in GMFM-D or TBM at 1-year. Lower pre-op TBM, fewer osteotomies, and longer time to post-op evaluation were associated with more improvement in ‘one-year’ functional mobility.

Table. Regression Analysis to predict short- and long-term mobility outcomes using surgical and patient factors n =58

	Acute Recovery (WeeFIM Mobility Change)					One-Year Recovery (PODCI Mobility Change)				
	Est.	**Adjusted Odds Ratio**	**2.5% CI**	**97.5% CI**	**p**	**Est.**	**Adjusted Odds Ratio**	**2.5% CI**	**97.5% CI**	**p**
Baseline target measure (WeeFIM or PODCI TBM)	-0.436	0.647	0.371	1.13	0.1208	-0.632	0.532	0.399	0.708	0.0001
PRE GMFM	0.233	1.26	1.06	1.5	**0.0104**	0.502	1.65	0.808	3.38	0.165
GMFCS level III	-0.354	0.702	0.0578	8.53	0.7754	0.427	1.53	0.000258	9110	0.9217
Number of Osteotomies	-0.0149	0.985	0.511	1.9	0.9635	-2.4	0.0907	0.00819	1	**0.0345**
IPR LOS / IPR Y/N	0.0286	1.03	0.683	1.55	0.8882	-3.55	0.0287	0.00000998	82.4	0.3745
DFEO Yes	0.33	1.39	0.102	18.9	0.7987	-0.46	0.631	0.000105	3800	0.9158
Age	-0.027	0.973	0.744	1.27	0.8396	-0.979	0.376	0.138	1.03	0.0559
months post	0.0593	1.06	0.858	1.31	0.5747	0.711	2.04	1	4.14	**0.0495**
WeeFIM Cognitive score	0.191	1.21	1.1	1.33	**0.0002**					



DISCUSSION

IPR after MLS was effective in promoting mobility gains during the acute recovery from MLS. During IPR, youth with cognitive impairment made less mobility gains. IPR after MLS was not associated with better long-term mobility or gait outcomes. Findings from this study are consistent with others showing improved gait pattern after MLS but not long-term mobility function. Further research examining risk factors for incomplete recovery and PT strategies to prevent loss and promote gains in mobility function after MLS is urgently needed.

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DISCLOSURE STATEMENT

Authors have no conflicts to disclose.

A Comparison of Different Insertion Approaches for Anterior Distal Femoral Hemiepiphysiodesis on Sagittal Knee Kinematics: A Case Series

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Introduction: Knee flexion contractures (KFC) are prevalent in children with cerebral palsy, which results in impaired gait limiting ability to ambulate independently. Anterior Distal Femoral Hemiepiphysiodesis (ADFH) surgery is an effective corrective procedure[1]. ADFH entails anterior tethering of the distal femoral physis and can be done with multiple different techniques. A common procedure is inserting two screws through the anterior third of the distal femoral physis, typically inserted superior to the physis (antegrade), however, the screws must transect soft tissue, impeding insertion parallel to the long axis of the femur. Our surgeons have developed a novel technique approaching inferior to the physis (retrograde) with limited tissue transection and a 'flatter' surface for screw insertion[2]. It is unknown how retrograde ADFH impacts sagittal knee kinematics during gait.

Clinical Significance: Both approaches increased peak knee extension angles during stance phase by ~6.4º between pre-operation and 2-year post-operation, demonstrating that retrograde improves peak knee extension angles similar to the established antegrade approach.

Methods: Four patients who underwent ADFH (2 antegrade, see Table 1) had a gait analysis preoperatively and 2 years post-operation. Kinematic and kinetic data was collected via 13 infrared cameras (Vicon, Oxford, UK) sampling at 120 Hz and 10 force plates (Bertec, OH, USA) sampling at 2160 Hz; utilizing a modified Helen-Hayes marker-set consistent with the conventional gait model. Sagittal knee angle was extracted for all strides (heel-strike to ipsilateral heel-strike) of the affected knee. Knee dynamic peak range was calculated as the difference between peak knee flexion and peak knee extension.

	Antegrade (n=2)	Retrograde (n=2)
Sex (n)		
Female : Male	1 : 1	0 : 2
GMFCS (n)		
I		1
II	1	1
III	1	
Average Age at Insertion (years)	8	10

Table 1. Patient demographics, stratified by insertion approach.

Results: See Figure 1 for a comparison of surgically treated mean knee sagittal angle waveforms stratified by antegrade and retrograde approach. Both approaches had a ~6.4º increase in peak knee extension from pre-operation to 2-year post-operation which translated to ~3.9º increase of dynamic peak range.

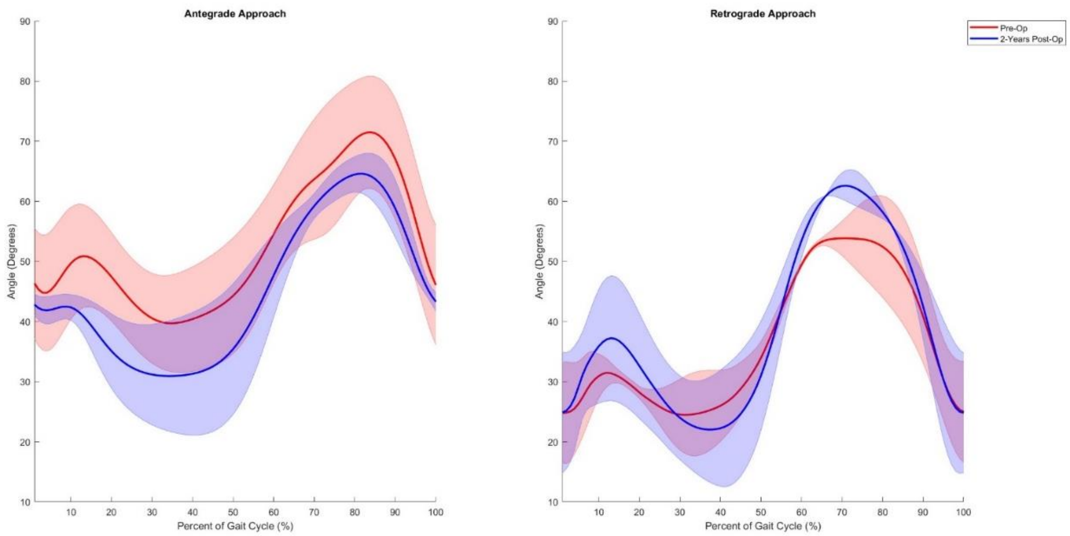

Figure 1. Sagittal Knee Angle. The solid line represents the mean of all strides collected of affected knees whereas the shaded line is the standard deviation. The bottom of the y-axis indicates knee extension and top indicates knee flexion (full extension is 0º). Dynamic peak range is a measure of peak knee extension, which occurs during mid-stance (30-50% of gait cycle), to peak knee flexion, which occurs during mid-swing (60-85% of gait cycle).

Discussion: Increases in peak knee extension and dynamic peak range during walking demonstrate that there is a similar improvement in functional outcomes for both antegrade and retrograde insertion approaches. Future research should examine gait following retrograde ADFH with a larger, adequately powered sample to confirm results observed in this case series. Additionally, long-term (i.e.,≥5 years) gait analysis should be performed to determine if improvements to gait are sustained as the individual continues to mature/grow. These findings continue to validate the retrograde insertion technique as an alternative approach to correcting KFC.

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THE ASSOCIATION BETWEEN ANTERIOR PELVIC TILT and BACK PAIN IN ADULTS WITH CEREBRAL PALSY

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INTRODUCTION:

Excessive anterior pelvic tilt (APT) is common in people with cerebral palsy (CP) and is thought to be associated with increased lumbar lordosis and back pain [1,2]. This assertion has prompted investigations of the risk factors for excessive APT, with hamstring surgery suggested as a causative factor [3]. However, the clinical significance of excessive APT, specifically with respect to back pain in adulthood, is unknown. The purpose of this study was to determine the association of APT—and other potential risk factors—with back pain in adults with CP.

CLINICAL SIGNIFICANCE:

This evaluation of APT and predictors of back pain in adults with CP can provide valuable insights for healthcare providers, particularly in guiding treatment decisions and surgical procedures that may influence APT.

METHODS:

Prospective call back cohort study of adults previously treated at a pediatric specialty center. Inclusion criteria were adults with CP greater than age 24, ambulatory (GMFCS I-IV), with at least one instrumented gait analysis (IGA) during childhood. The primary outcome was the prevalence of back pain. Secondary outcome was the degree of APT [determined by IGA; stratified as high (>20˚), medium (11-20˚), low (<11˚)]. Other kinematic parameters (trunk tilt, lordosis, stance knee flexion), PROMIS pain interference score, walking activity (by StepWatch™), and Gait Deviation Index (GDI) were examined as potential risk factors for back pain. Chi-squared tests compared the association of back pain to APT. Regression analysis was utilized to determine risk factors for back pain.

RESULTS:

One hundred-eighteen patients (42% female) met the inclusion criteria: GMFCS level I (n=24), II (n=64), III (n=24), IV (n=6); mean age 29±4 years, range 24 to 44 years. The prevalence of back pain was 14% (n=16) for the entire cohort. The degree of APT was not significantly different between groups with and without back pain (20.6±10.4 vs 19.4±9.1; p=0.99). The prevalence of back pain by APT severity was also not different (high=15%; medium=13%, low=11%; p=0.94). Regression analysis found that neither APT nor the secondary factors of interest were significant predictors of back pain (Table).

Table: Regression analysis predicting back pain in young adults with CP.

	Est.	**Adjusted Odds Ratio**	**2.5% CI**	**97.5% CI**	**p**
Age	-0.014	0.99	0.85	1.13	0.85
Body Mass Index	-0.064	0.94	0.81	1.06	0.35
GMFCS II	0.035	1.04	0.17	6.85	0.97
GMFCS III	2.1	8.00	0.58	126	0.12
GMFCS IV	-0.13	3.81×10^{-6}	NA	1.52×10^{32}	0.99
Popliteal Angle	0.022	1.02	0.98	1.07	0.30
Knee extension PROM	0.058	1.06	0.95	1.19	0.30
Leg length discrepancy	-0.18	0.83	0.36	1.66	0.64
Knee flexion during stance phase in gait	-0.0018	0.99	0.92	1.09	0.97
Anterior Pelvic Tilt during gait	0.22	1.25	0.92	1.75	0.17
Anterior Trunk Tilt during gait	-0.29	0.75	0.53	1.02	0.08
Gait Deviation Index	-0.0079	0.99	0.92	1.08	0.84
Lordosis	0.14	1.15	0.91	1.49	0.25
Gait velocity (cm/s)	0.0062	1.01	0.98	1.04	0.69

DISCUSSION:

Despite clinicians' concerns, excessive APT was not significantly associated with back pain in this cohort of adults with CP. With a reported prevalence of approximately 30% in non-disabled adults, the risk of back pain in CP may in fact be lower. The negative consequences of excessive APT in CP may not be as significant as previously thought.

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NO DISCLOSURES

3D-Instrumented Gait Analysis for Surgical and Rehabilitative Treatment Decisions in Children with Cerebral Palsy: Results from a 2024 Clinical Practice Guideline

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Background: Ambulatory children with cerebral palsy (CP) often present with complex gait patterns and deviations requiring surgical and rehabilitative interventions. Such decisions can be assisted by the inclusion of three-dimensional instrumented gait analysis (3D-IGA) providing kinematics, kinetics and muscle activity. To summarize, synthesize, and appraise the body of literature surrounding the clinical utility of 3D-IGA for ambulatory children with CP, a clinical practice guideline (CPG) was developed with seven action statements.[1] The CPG links the action statement grades with specific levels of evidence based on a critical appraisal of the literature. Two of the action statements highlight how the inclusion of 3D-IGA data informs surgical and rehabilitative interventions, as well as, how the inclusion of data for decision making impacts post-interventional outcomes.

Purpose: To summarize the existing literature describing how the inclusion of 3D-IGA data impacts surgical and rehabilitative decisions and improves post-interventional outcomes.

Methods: The literature search was completed in September 2022. Searches were performed using the following databases: Ovid/MEDLINE, EMBASE, the Cumulative Index to Nursing and Allied Health Literature (CINAHL), the Physiotherapy Evidence Database (PEDro), the Cochrane Database of Systematic Reviews, and the Cochrane CENTRAL database. Studies included for the two current action statements were randomized-controlled trials and quasi-experimental studies. Data extraction included study characteristics, surgical and rehabilitative interventions considered, documented alterations in the plan of care resulting from the inclusion of 3D-IGA data, and outcome comparison(s) between groups whose interventions were determined either with or without the including of 3D-IGA data. Experimental studies were appraised with the Critical Appraisal Tool for Experimental Interventions (CAT-EI V1.2). BRIDGE-Wiz software was used to assure that action statements aligned with the Institute of Medicine's standards for transparency through its process and the template of headings. The evidence quality for each action statement was assigned through consensus of the authors based on the APTA Clinical Practice Guideline Manual.

Results:
Action Statement: Informing Surgical Interventions: Physical therapists, physicians, and related clinicians should recommend 3D-IGA when a child with CP who is ambulatory with or without an assistive mobility device is considered for surgery to improve gait function. (Evidence Quality: II, Rec. Strength: Moderate). *Aggregate Evidence Quality*: Level II based on two moderate quality randomized controlled trials (RCTs) reported in three publications and eight low quality quasi-experimental studies

Supporting Evidence and Clinical Interpretation: Nine studies were included where incorporating 3D-IGA into surgical planning for children with cerebral palsy influenced decision-making, often leading to changes in planned procedures. One randomized controlled trial (RCT) showed that 3D-IGA significantly altered surgical plans, resulting in the elimination of unsupported procedures and increased adherence to recommended ones. Other studies, despite lacking control groups, consistently found that surgical plans changed after 3D-IGA, with adjustments varying across muscle and bone surgeries. Additionally, one study highlighted 3D-IGA's potential to identify children who may not require surgery.

Post-surgical outcomes also improved when 3D-IGA recommendations were followed, as demonstrated by one RCT and several quasi-experimental studies. Patients who underwent surgeries guided by 3D-IGA had better gait outcomes and functional improvements, though adherence to gait analysis recommendations was often low. Cost studies suggested that while initial surgical costs were higher with 3D-IGA, it led to fewer subsequent surgeries and lower long-term healthcare costs. Overall, evidence supports the integration of 3D-IGA into clinical decision-making for optimizing surgical outcomes and resource utilization in children with CP.

Action Statement: Rehabilitative Interventions: Physical therapists, physicians, and related clinicians may recommend 3D-IGA to inform non-surgical interventions for children with CP with gait dysfunction whose progress from rehabilitative interventions and conservative management has plateaued or shown substantial deterioration. (Evidence Quality: III; Rec. Strength: Weak). *Aggregate Evidence Quality:* Level III based on two high quality studies with methods that precluded direct application to the question of interest.

Supporting Evidence and Clinical Interpretation: Two studies across four articles examined the impact of 3D-IGA on non-surgical interventions compared to similar treatments without 3D-IGA. While both studies were randomized controlled trials, their design limitations obscured the direct influence of 3D-IGA on outcomes. A small pilot study with 10 children and later expanded to 40, found only minor improvements in select gait parameters for the 3D-IGA-informed group. However, similarities in treatment activities between groups reduced the study's ability to demonstrate a clear benefit. Another study included 60 participants but found no significant differences between groups in gait quality or patient-reported outcomes, with low adherence to treatment recommendations further limiting findings. A secondary analysis also found no significant effects on care process measures. Overall, while individualized interventions based on 3D-IGA showed potential for small benefits, study limitations and inconsistent adherence weakened the evidence supporting its impact on non-surgical treatment outcomes.

Discussion/Conclusion: A systematic review of the literature resulted in a CPG that includes seven graded action statements with varying levels of obligation that describe the role of 3D-IGA in the clinical management of ambulatory children with CP who present with gait dysfunction. Of these statements, two of the action statements highlight 3D-IGA's utility to inform surgical and non-surgical interventions. Overall, the existing literature supports the use of 3D-IGA data for orthopedic surgical planning as it has altered the surgical plan, improved post-operative outcomes, and reduced the long-term cost of care. Less support exists in the literature for the role of 3D-IGA data for planning of rehabilitation interventions beckoning for continued research in this area. These action statements can provide guidance to clinicians and families when considering both surgical and rehabilitative care of ambulatory children with CP.

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ACKNOWLEDGEMENTS:

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DISCLOSURES:

None

Relationship between Upper Extremity Reachable Workspace Measures and Patient-Reported Outcomes in Brachial Plexus Birth Injury and Cerebral Palsy

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INTRODUCTION

Neuromuscular conditions, such as brachial plexus birth injuries (BPBI) and cerebral palsy (CP), frequently result in lifelong deficits in upper extremity (UE) function. Accurate measurement of the entirety of an individual's UE function is essential for informing patient-specific decision-making and outcomes assessment. Current evaluative tools, such as clinical functional assessments and motion capture evaluations, rely on a limited set of UE postures and/or movements and emphasize joint-level function to focus on how a patient performs those tasks. Consequently, these assessments fail to comprehensively assess the entirety of a patient's UE abilities and do not align well with patient-reported outcomes (PROs) [1].

By contrast, reachable workspace (RWS) provides an assessment of global UE function by quantifying the regions that patients can reach with their hands to answer can, not how, a patient achieves a given hand position [2]. Thus, RWS provides a more holistic appraisal of global UE function that may align more closely with PROs than existing measures of function. Outer, far-from-body RWS can distinguish between affected/injured and healthy limbs for various UE populations including BPBI [3] and RWS has recently been used to assess inner, close-to-body mobility [4]. Minimal work, however, has been completed on the relationship between RWS and PROs [5], and none specifically on BPBI or CP.

This study compared outer, far-from body and inner, close-to-body RWS measures against two UE PRO tools – Pediatric Outcomes Data Collection Instrument (PODCI) and Patient-Reported Outcomes Measurement Information System (PROMIS). It was hypothesized that RWS measures would correlate with PODCI and PROMIS for both the BPBI and CP cohorts.

CLINICAL SIGNIFICANCE

RWS provides a more global assessment of UE mobility that may align more closely with patient-perceived function than clinical functional assessment or motion capture evaluations.

METHODS

Trunk and UE segment orientations on the affected limb of 23 children with BPBI (3-15 years; variety of injury levels) and 12 children with spastic, hemiplegic CP (7-17 years; GMFCS level I-II) were measured with motion capture. Virtual targets were created with anatomically scaled radii for outer, far-from body and inner, close-to-body regions (**Fig. 1 A/B**). Custom software displayed targets and real-time movement of a red cursor sphere controlled by hand position relative to the torso measured by motion capture (**Fig. 1 A/B**). Targets were displayed sequentially

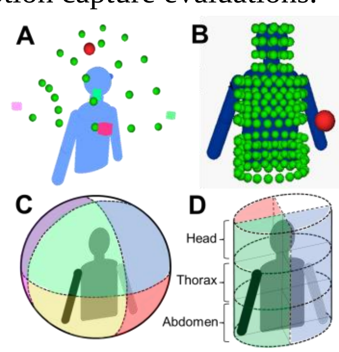

Figure 1: real-time feedback displayed regions for outer (A/C) and inner (B/D) workspace.

by region (e.g., superior/anterior/ipsilateral) for all outer regions (**Fig. 1C**) or by primary inner region (head, thorax, abdomen) (**Fig. 1D**) until all targets were completed or no more could be reached. Percentage workspace reached was calculated for each outer and primary inner region as well at total outer and total inner workspace, which were an average of all outer and inner region values, respectively. Each patient or their parent proxy completed PODCI and PROMIS surveys. Pearson correlations were calculated between percentage workspace reached in each region and each PRO measure.

RESULTS

Significant moderate ($0.4<r<0.7$) to strong ($r>0.7$) correlations were found between RWS measures and PODCI UE and PODCI Global scores in BPBI (**Table 1**). No significant correlations were found between RWS measures and PROMIS scores in BPBI (**Table 1**). Only weak ($r<0.4$) to moderate, non-significant correlations were found between RWS measures and PODCI or PROMIS measures in CP.

Table 1: Correlation coefficients between % RWS reached for various regions and PROs in BPBI. * $p<0.05$, † $p<0.01$.

Region (% Reached)	**PODCI UE (n=23)**	**PODCI Global (n=20)**	**PROMIS Mobility (n=21)**	**PROMIS UE (n=21)**
Total Outer RWS	0.423 *	0.393	0.332	0.345
Total Inner RWS	0.581 †	0.460 *	0.157	0.364
Head RWS	0.329	0.239	0.190	0.384
Thorax RWS	0.719 †	0.461 *	0.098	0.299
Abdomen RWS	0.512 *	0.560 *	0.078	0.202

DISCUSSION

Stronger correlations between RWS and PODCI UE versus PODCI Global are likely due to the PODCI UE questions focusing solely on UE function compared to those of the more general PODCI Global. PODCI UE questions mostly pertain to close-to-body tasks that are performed below head level (e.g., opening a jar, writing, etc.), which may explain its stronger correlations with the thoracic and abdominal regions of inner RWS. The CP cohort was mildly affected, which may have contributed to the lack of significant correlations between RWS and PROs. The BPBI patients were younger (<10 years) and all but one required a parent proxy to complete the PROs. The CP cohort was older with only 3 of 12 requiring a parent proxy for PROs. Thus, the significant and non-significant correlations between RWS and PROs in BPBI and CP, respectively, may highlight a key difference between a patient’s and their parent’s perception of UE function. This study provides evidence that RWS aligns with some PROs for BPBI but not CP, however, more work is needed to fully understand these relationships.

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DISCLOSURE STATEMENT

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FEASIBILITY OF MARKERLESS MOTION CAPTURE FOR ASSESSING GAIT IN DIVERSE CLINICAL, PEDIATRIC POPULATIONS

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INTRODUCTION: Markerless motion capture leverages machine learning for pose estimation, and offers a supplement or alternative to the current, "gold standard" of marker-based systems. Validating that markerless is just as accurate or precise for clinical use could make clinical gait analysis more portable, less training-intensive, and more accessible to patients. Indeed, markerless systems appear to have relatively good agreement to marker-based in healthy adults [1] and pediatric populations [2]. The purpose of this study was to add to this body of validation work by comparing marker-based to markerless systems in a large cohort of pediatric patients with varied diagnoses and to investigate the agreement of these systems across the gait cycle.

CLINICAL SIGNIFICANCE: Markerless motion capture could provide an alternative to marker-based systems, making pediatric clinical gait analysis more accessible to more diverse patients populations; however, it requires rigorous validation.

METHODS: Reflective markers were placed on the patient during a clinical gait evaluation according to the Shriners Children's Gait Model (SCGM) template [3] by certified physical therapists. Each visit consisted of a static standing trial, a dynamic knee alignment check, and a series of dynamic walking trials. Patients completed at least three barefoot walks while using their ambulation aid. A marker-based motion capture system comprised of 12 infrared cameras (Vicon Vantage V16) tracked reflective markers (60 Hz). Eight FLIR cameras (Teledyne Blackfly) concurrently captured digital video (60 Hz) for a markerless system (Theia3D). The SCGM calculated marker-based joint angles [3], and Theia3D computed the transformation matrices for the markerless data which were then used to calculate comparable joint angles. Altogether, 12 kinematic variables were estimated bilaterally (i.e., about the pelvis, hip, knee, and ankle). Three strides per side per patient were analyzed. Both the marker-based and markerless outputs were resampled to consist of 101 data points per gait cycle. Comparisons between the marker-based and markerless outputs were made using Root Mean Square Error (RMSE) [2] and Statistical Parametric Mapping (SPM) [4], [5] for each kinematic variable. RMSE provides a coarse estimate of agreement during the gait cycle, on average, while SPM offers an estimate of agreement between systems throughout the gait cycle.

RESULTS: The sample of patients ($n = 132$; 71 males; 12.52 ± 4.02 yrs) was relatively balanced with regards to age, BMI, and use of an ambulation aid. The most common diagnoses were cerebral palsy, arthrogryposis, and talipes equinovarus for each sex. The Average RMSE values were < 6° except pelvic tilt, hip flexion/extension and rotation, knee rotation, and foot rotation. RMSE was not appreciably affected by laterality, sex, or age (Fig. 1A). Adding an assistive device tended to increase RMSE by approximately 2°, with the largest differences at the hip and pelvis. RMSE was also larger by approximately 2-5° at the hip and pelvis for patients categorized as "Obese" (BMI > 30) as compared to "Underweight," "Normal," and "Overweight" patients (Fig. 1B). While all 12 kinematic variables differed significantly between systems at least at one point during the gait cycle ($p < 0.05$) (Fig. 1C), only bilateral pelvic tilt, hip flexion/extension, foot progression, and right knee rotation differed at all points during the gait cycle ($p < 0.01$).

DISCUSSION: Marker-based and markerless motion capture are overall comparable, and few kinematic outcomes vary between the two systems across the complete gait cycle. Of note, the pelvis and hip exhibited the largest differences presented here; however, these may have been due to assumptions made by the Theia3D pelvis model that have been addressed in a recent update. We are actively working to address this in the presented dataset. That said, considerable work still must be done to characterize the factors that influence markerless accuracy in pediatric populations, and a normative dataset must be established prior to its implementation clinically.

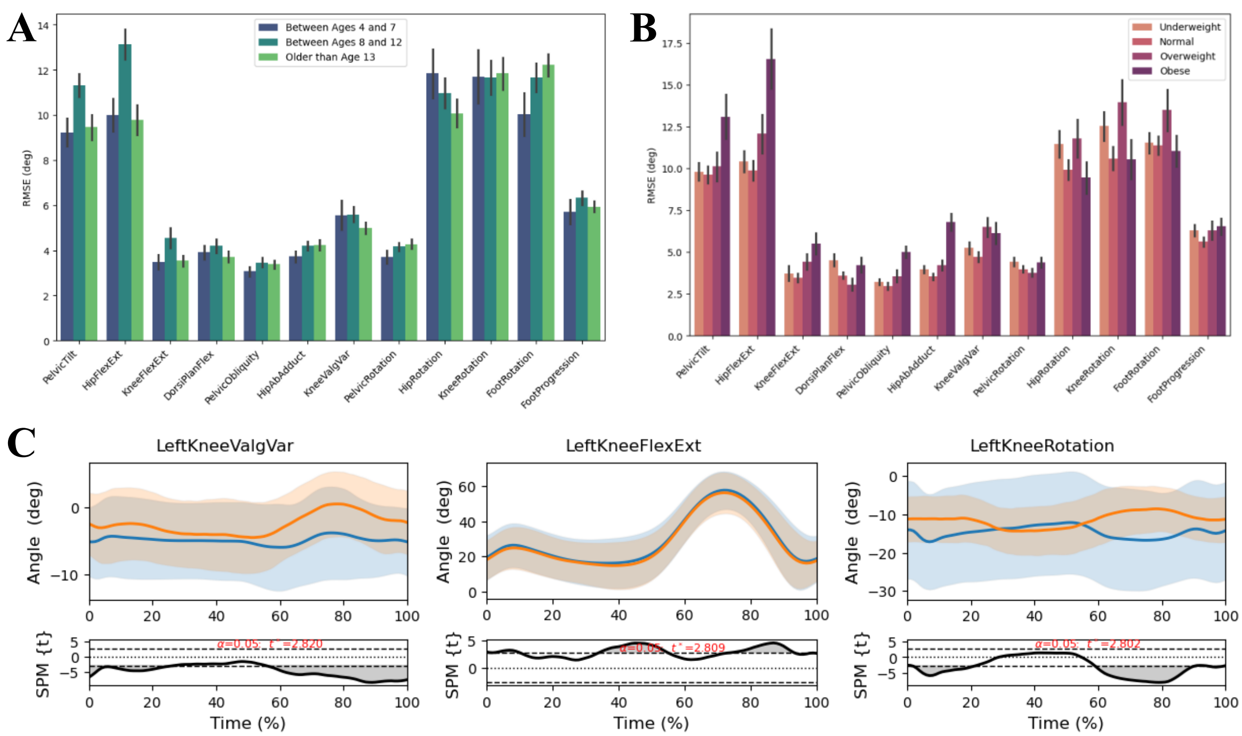

Figure 1. Average RMSE of each joint angle by **A)** age group and **B)** BMI. **C)** Average angles (*top*) and SPM results (*bottom*) for left knee varus/valgus (*left*), flexion/extension (*center*), and rotation (*right*). Marker-based (blue) vs. markerless (orange).

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Assessing Balance and Stability in Individuals with Prune Belly Syndrome

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INTRODUCTION

Prune belly syndrome (PBS), also referred to Eagle-Barrett syndrome, is a rare and medically complex congenital myopathy characterized by deficient or absent ventral abdominal wall skeletal musculature, urinary tract distension, and intra-abdominal testes [1, 2]. Approximately 1500 US children are currently living with this syndrome, with 95% of cases occurring in males [2, 3]. PBS severity ranges from mild to lethal, with a phenotypic spectrum of abdominal wall weakness and laxity often managed surgically. PBS ventral abdominal wall is most deficient in musculature centrally, whereas it may be normal laterally.

Balance is the process by which an individual maintains postural stability and is a key determinant of mobility, functional independence, and overall quality of life. Core musculature plays a crucial role in balance by providing stability and trunk support. Those with compromised balance may face functional limitations, such as limited mobility, reduced independence and social participation due to fear of falls [4]. Literature is limited on the functional impairments seen in those with PBS caused by the deficient abdominal wall musculature with or without static or dynamic abdominoplasty. Thus, it is important to be able to assess balance in this clinical populations to improve therapeutic and rehabilitation outcomes in this group.

CLINICAL SIGNIFICANCE

There is limited information on the functional mobility limitations in individuals with PBS. There are no clear objective measures of abdominal wall function in PBS and the need for and outcomes of abdominoplasty surgery have not been rigorously studied. Understanding these impairments could provide critical insights for the development of targeted rehabilitation strategies and interventions aimed at improving balance, reducing fall risk, and enhancing the overall well-being of individuals with PBS.

METHODS

This is a cross-sectional observational study utilizing 3-D motion capture and force plate technology to assess balance and stability in individuals with PBS. Seven patients (age 7-34 years old, 86% male) with PBS were enrolled in this study and completed a one-time visit to a motion analysis lab. Abdominoplasty status included static (n=2), dynamic (n=1), no surgery (n=3), and unknown (n=1). Fourteen typically developing (TD) controls were recruited for comparison (age 9-35 years old, 71% male). Participants completed the sharpened Romberg and Pediatric Reach Test (PRT) on a force platform to evaluate the center of pressure (CoP) during these tests. Non-parametric data was analyzed using a Mann-Whitney U test and Spearman's rank-order correlation coefficient.

RESULTS

There were no differences in age or sex distribution between the PBS and control groups (p=0.681, 0.489). During the sharpened Romberg, in the preferred, feet together, and semi-tandem stance, there were no balance parameters that were statistically different between groups. During tandem stance, the PBS group had a greater CoP medial-lateral (ML) and anterior-posterior (AP) range ($p<0.01$, $p=0.037$), average ML velocity ($p=0.048$), and ellipse area ($p=0.037$). During the PRT, the control groups had a forward reach that was 19% of their wingspan, whereas the PBS group reached 25% of their wingspan, although this was not a statistically significant difference ($p=0.488$).

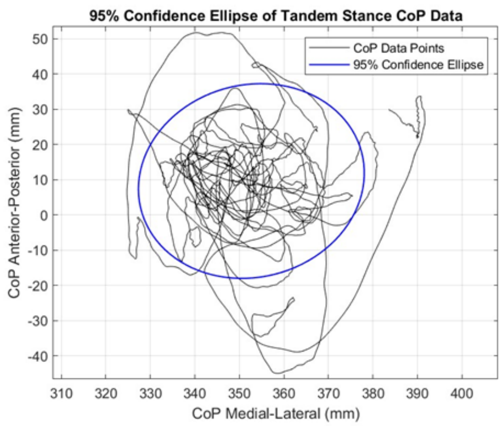

Figure 1: Ellipse area representing 95% of the CoP data points during tandem stance of a patient with PBS

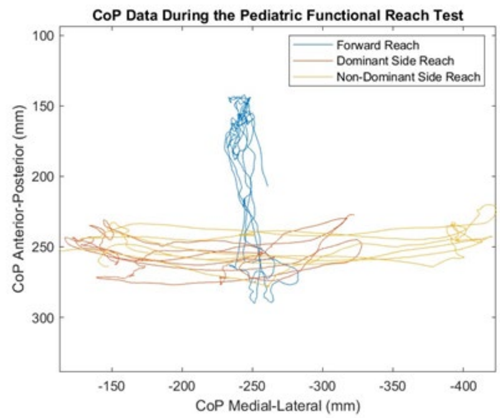

Figure 2: CoP data during the PRT from an individual with PBS during the forward and lateral reaches

DISCUSSION

This study presents the first evidence of balance deficits in patients with PBS using advanced 3D motion capture technology. Although static and dynamic were generally similar to TD controls in most scenarios, specific deficits became apparent under challenging conditions, such as tandem stance, suggesting subtle instabilities that could impact real-world function. Given the ventral abdominal wall deficiencies are greater centrally than laterally, this corresponds with the results seen in the PRT where the forward reach demonstrates more impairments than the lateral reach; however, further analysis into the specific biomechanics of the reach is warranted.

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DISCLOSURE STATEMENT

Kirsten Tulchin-Francis is a board member of GCMAS.

CAN SINGLE-LEG CROSSOVER DROP LANDING MECHANICS PREDICT A SECOND ACL INJURY?

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INTRODUCTION

Anterior cruciate ligament (ACL) injuries continue to pose a substantial challenge in sports medicine, with a high risk of second injury post-reconstruction. While return-to-sport assessments often focus on strength and neuromuscular testing, they may overlook underlying biomechanical deficits that contribute to re-injury. The single-leg crossover drop landing is a dynamic movement that emphasizes lateral trunk bending, knee valgus, and increased external load on the knee, each of which are traditionally associated with the increased risk of ACL tear.

Research indicates that single-leg landings result in higher joint loads and altered movement patterns compared to double-leg landings [1]. Specifically, vertical jump assessments are known to reveal neuromuscular deficits and biomechanical asymmetries in ACL reconstruction athletes even when symmetrical limb performance have been restored [2], [3]. Assessing single-leg crossover drop landing mechanics provides valuable insight into neuromuscular control and lower extremity differences, offering a more comprehensive evaluation of athlete readiness to return-to-play. Given the high rates of second ACL injuries, predicting these injuries through specific dynamic movements could allow focus on key variables in clinical assessments and rehabilitation.

CLINICAL SIGNIFICANCE

Use of single-leg crossover drop landing as a method to predict reinjury in individuals post-ACL reconstruction surgery may enhance the criteria for return-to-sport assessments across different athletic populations. This approach has the potential to advance ACL research, ultimately identifying crucial factors that can inform future therapeutic and rehabilitation strategies.

METHODS

98 athletes post-ACL reconstruction surgery (Median age at surgery 16.6 [15.2,19.8] yrs., median months from surgery to testing: 11 [9.5,13.6], height: 170±6.7 cm, mass: 68.9±13.9 kg) successfully completed motion analysis evaluations at the completion of a multicenter clinical trial (Emory University, Cincinnati Children's, Mayo Clinic, The Ohio State University). Participants were verbally asked to balance on a non-injured on top of a 31 cm box. They were then asked to drop off of that box and land on their injured leg after swinging it across the front of their body during the drop. Data was captured with a modified Helen Hayes markerset (n=55). Motion capture and force data were collected using 14-40 camera systems sampled at 100-240 Hz and Bertec force plates at 1000-1200 Hz. Higher rate collections were down sampled to 100 Hz and 1000 Hz, respectively, and post-processed in Visual3D using a recursive, fourth-order, low-pass digital Butterworth filter with a cutoff frequency of 50 Hz.

Peak kinematics and kinetics of the involved limbs ankle, knee and hip were imported into JMP 17 Pro (Cary, NC). These variables (n=192) were entered into a forward Stepwise selection process for a nominal regression for predicting second injury using the minimum AICc criterion stopping rule. From the selection process, 38 of the variables entered the model. The variables were systematically eliminated based on their non-significance, resulting in a final selection of 10 remaining variables. The predictor rate was calculated based on true positive and true negatives divides by the total of positives and negatives, respectively.

RESULTS

The nominal regression demonstrated an AUC of 0.88 with a specificity of 87.6% and a sensitivity of 75%. The model demonstrated a 56.8% positive predictor rate with a true negative rate of 97%. This model has an overall 'good' performance. The sensitivities and specificity of the model was high but difficult to predict 2nd ACL injuries.

Table 1. Effect summary of the nominal logistic fit for individuals with a 2nd ACL injury.
** denotes statistically significant variables*

Peak Variable	**Logworth**	**p-value**
Extension Trunk Angle	7.990	p<0.001*
Hip Moment Abduction Range of Motion	7.437	p<0.001*
Abduction Hip Angle	6.804	p=0.002*
External Rotation Hip Angle	4.402	p<0.001*
Frontal Plane Hip Power	4.240	p<0.001*
Abduction Knee Angle	4.192	p<0.001*
Adduction Knee Angle	2.646	p=0.002*
Internal/External Knee Angle Range of Motion	2.601	p=0.03*
External Rotation Ankle Angle	1.538	p<0.001*
Plantarflexion Ankle Angle	1.496	p=0.029*

DISCUSSION

The data demonstrates the importance of ankle, knee, hip, and trunk angles, power, and range of motion during single-leg crossover drop landing. The current data is still being tracked for up to five years, although a minimum of only one year of post-intervention data is currently available for all subjects that were enrolled in the clinical trial. Due to the limited sample size of individuals experiencing a second ACL injury, it is important to interpret the results with caution. Additional follow-up and research are necessary to monitor participants after sustaining a second ACL injury. It is possible that, due to their history of ACL injury, these individuals may exhibit unique landing strategies, particularly in the moments generated prior to landing. Therefore, future research should continue to explore these differences, specifically within the context of individuals who have experienced a second injury.

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DISCLOSURE STATEMENT

No conflicts of interest to disclosure

Biomechanical and Functional Outcomes of High and Low Burden Multi-Level Surgery in Youth with Cerebral Palsy

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INTRODUCTION Multilevel orthopedic surgery (MLS) intends to correct all levels of biomechanical deformity in a single episode to optimize gait in youth with cerebral palsy (CP). Many clinical studies identify improvement in gait kinematics after MLS. Our laboratory categorizes MLS based on the physiologic burden of recovery, in which high burden (HB-MLS) describes episodes with ≥ two osteotomies and low burden (LB-MLS) those with ≤ one osteotomy, both with any LE soft-tissue surgeries.

CLINICAL SIGNIFICANCE Work from our lab shows that youth with HB-MLS take longer to regain baseline level of walking activity (WA) compared to LB-MLS. The current study aims to build on that work, comparing 2-year outcomes of gait biomechanics and mobility function in HB vs. LB-MLS.

METHODS In this IRB approved retrospective study, ambulatory children with spastic CP were identified from our gait lab database from 2008 to 2024. The outcome for gait pattern was Gait Deviation Index (GDI) and outcome measures for mobility function were the Gross Motor Function Measure-88, dimension D (GMFM-D), gait velocity, and the Pediatric Outcomes Data Collection Instrument (PODCI). Pre-and post-op outcome measures were compared using paired t-tests; the effects of surgical burden and preoperative factors on change in outcome measure were evaluated using regression analysis.

RESULTS 287 youth were included. 178 surgical events were LB-MLS [GMFCS level I (n=30), II (n=104), and III(n=44)] and 139 were HB-MLS [GMFCS level I (n=12), II (n=79), and III(n=48)]; with mean ages at surgery of 11.4±4.1 and 13.6±3.0 years, respectively. Youth in the LB group had 3.7±2.5 procedures per event and youth in the HB group had 6.9±3.2 procedures per event. GDI improved in both the LB ($p<0.001$) and HB ($p<0.001$) groups. Functional outcomes differed between the LB and HB groups. Only the LB group exhibited gains in GMFM-D ($p<0.001$). The LB group exhibited faster post-op gait velocity ($p<0.01$) while HB exhibited slower velocity ($p<0.01$). Both the LB ($p<0.001$) and HB ($p<0.05$) groups exhibited post-op improvements in PODCI. In the regression analyses for each of the four outcomes (GDI, GMFM, gait velocity, PODCI), baseline value of the target outcome were significant predictors of change ($p<.001$). Additionally, GMFCS level was a significant predictor for change in GDI, GMFM-D, and Gait Velocity ($p<.001$ to .03). Surgical burden was a significant predictor for change in GMFM-D and gait velocity ($p<0.001$).

DISCUSSION While improved gait pattern is expected after HB and LB-MLS in youth with CP, clinicians and families should understand that gains in mobility function are less likely after HB-MLS. These results will improve shared decision, assist in managing expectations and spark study of approaches to modify functional outcomes after HB-MLS in ambulatory youth with CP.

Paired Sample T-tests												
	GDI			GMFM-D			Gait Velocity			PODCI		
	Pre (SD)	Post- (SD)	p	Pre (SD)	Post (SD)	p	Pre (SD)	Post (SD)	p	Pre (SD)	Post (SD)	p
LB Surgery	**67.0 (16.0)**	**73.2 (14.9)**	**<0.001**	**29.2 (8.3)**	**30.7 (6.9)**	**<0.001**	**83.4 (27.2)**	**87.9 (27.4)**	**<0.01**	**68.5 (16.0)**	**72.4 (15.2)**	**<0.001**
HB Surgery	**67.0 (14.3)**	**70.7 (12.9)**	**<0.001**	27.4 (7.9)	26.8 (7.8)	0.13	**76.3 (27.7)**	**71.2 (31.4)**	**<0.01**	**65.1 (15.9)**	**67.4 (16.2)**	**<0.05**
Regression Analysis												
Model Type	Mixed Effects (GDI)			Linear Regression (GMFM)			Linear Regression (Gait Velocity)			Linear Regression (PODCI)		
	Coeffic	SE	p	Coeffi	SE	p	Coeffic	SE	p	Coeffi	SE	p
Burden (L)	1.91	2.48	1.00	**1.84**	**0.53**	**0.00**	**9.59**	**2.69**	**0.00**	0.08	0.06	0.17
Prior surgery	0.99	1.19	0.4	0.05	0.54	0.92	2.74	2.74	0.45	0.01	0.06	0.82
Baseline Target Measure	**-0.61**	**0.04**	**0.00**	**-0.55**	**0.06**	**0.00**	**-0.42**	**0.07**	**0.00**	**-0.65**	**0.09**	**0.00**
GMFCS II	**-4.42**	**2.09**	**0.03**	**-2.9**	**1.04**	**0.01**	**-12.06**	**5.33**	**0.02**	0.00	0.1	0.98
GMFCS III	**-10.36**	**2.98**	**0.00**	**-7.42**	**1.44**	**0.00**	**-25.12**	**7.34**	**0.00**	0.12	0.15	0.42
Pattern (Uni)	1.72	1.87	0.36	0.62	1.05	0.56	0.37	5.38	0.94	0.11	0.11	0.33
Gender (M)	1.01	1.13	0.37	0.48	0.52	0.35	1.99	2.64	0.45	0.08	0.06	0.15
Age at surgery	0.07	0.16	0.65	**-0.15**	**0.07**	**0.05**	-0.58	0.38	0.13	-0.01	0.01	0.07

Table: T-Tests/ Multiple Regression for Biomechanical and Mobility Function Outcomes

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Investigation of the Head-Shake Sensory Organization Test (HS-SOT) in the Yaw Plane

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INTRODUCTION

The sensory organization test (SOT) is commonly used to identify balance impairments in different sensory conditions. Patients with compensated disorders, athletes, and individuals with high-demanding occupations often do not show SOT impairments despite expressing dysfunction in daily activities [1,2,3]. Adding head motion to the SOT increases postural control demands, potentially improving test sensitivity to detecting balance impairments [1]. The purpose of this study is to investigate the effect of head motion on SOT equilibrium scores and head velocities.

CLINICAL SIGNIFICANCE

In the head-shake sensory organization test (HS-SOT), the subject repeats two of the SOT conditions while moving the head in the yaw, pitch, or roll plane. Increasing functional demand through incorporating the head shake may help in identifying subtle balance impairments not detected in the standard SOT. This aspect of the HS-SOT has been used for early detection of postural instability and post-injury intervention to facilitate return to work or play [2]. The current study provides the newest normative values for head velocities, equilibrium scores (ES) and equilibrium score ratios (ESR) on Bertec's computerized dynamic posturography (CDP) system, while demonstrating the increasing difficulty of the HS-SOT compared to the SOT. These findings support the addition of the HS-SOT into testing protocol as a more sensitive evaluation to detect balance impairments overlooked by standard balance tests.

METHODS

Twenty subjects (age: 28±6, 13M, 7F) performed the HS-SOT on the CDP with immersive virtual reality (CDP/IVR by Bertec Corporation, Columbus, Ohio). The amplitude and velocity of yaw (side to side) head movements were measured with an inertial measurement unit; a metronome and examiner cues provided auditory feedback to help maintain the prescribed motion. The target amplitude and velocity were 20° and 85°/sec respectively. Two SOT conditions, eyes closed on firm support (SOT2) and eyes closed on sway-referenced support (SOT5), were performed and then repeated while moving the head (HS-SOT2 and HS-SOT5, respectively). Mean ES and their ratios (ESR, calculated as HS-SOT/SOT) were determined for each condition. Mean peak head turn velocities (HTV) in the left and right directions for the HS-SOT tests were also calculated. A repeated-measures ANOVA was conducted for each ES condition; a Welch's t-test was used to evaluate differences in HTV between head-shake conditions and between left and right HTV within each condition.

RESULTS

ES values are represented in Table 1. Condition 2 ESR (0.996±0.043) was significantly larger (p<.001) than condition 5 ESR (0.752±0.168). No violations of

Table 1: ES values by condition

Condition	ES
SOT2	$92.75 \pm 2.75^{b,d}$
HS-SOT2	$92.36 \pm 2.85^{b,d}$
SOT5	$75.17 \pm 5.83^{a,c,d}$
HS-SOT5	$56.55 \pm 11.86^{a,b,c}$

[a]: significantly different than SOT2; [b]: significantly different than SOT5; [c]: significantly different than HS-SOT2; [d]: significantly different than HS-SOT5

normality (p>.05) occurred for any variable; a Greenhouse-Geisser correction was applied to the ANOVA due to a sphericity violation (p<.001). Test condition had a significant impact on ES ($F(3,60) = 168.65$, $p<.001$, $\eta^2 = 0.849$). No differences in HTV were found between conditions for left (p=.194) or right (p=.173) sides. A significant difference was found between left and right velocities for both the HS-SOT2 (p=.005) and HS-SOT5 (p=.008), shown in Fig. 1.

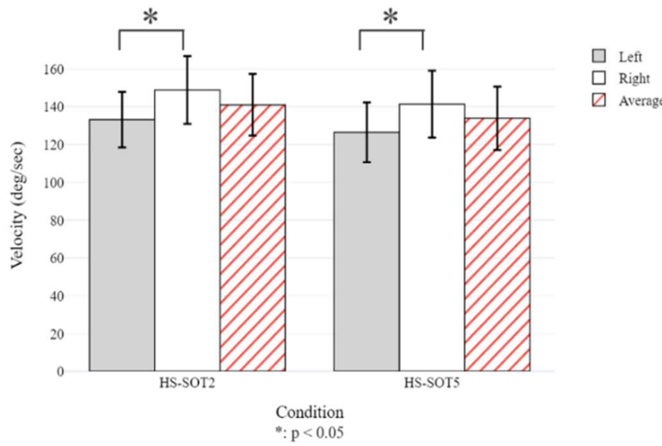

Figure 1: HTV by condition

DISCUSSION

Our ES and ESR results are consistent with previous studies [2,3] that utilized the NeuroCom CDP. To our knowledge, this is one of the first to report HS-SOT results using the Bertec CDP. Accurate perception of our relationship to the world and postural orientation relative to gravity is crucial to precise motor control; as such, careful testing and training of our internal balance systems is imperative to healthy living. Post-hoc analysis of our data showed significant differences between SOT5 and HS-SOT5 but not for SOT2 and HS-SOT2. This suggests the proprioceptive cues allowed in the SOT2 conditions were strong enough to overcome vestibular disruption caused by the turning the head. Previous research shows adding the head turn task to the SOT increases attentional demands [1,2], subtly changes biomechanical and neural relationships of the head and neck [3], and increases demand on the vestibular system [1,2,3]. Differences present between the condition 5 tests demonstrate the capacity for the HS-SOT5 to better isolate vestibular contributions compared to the HS-SOT2.

Regarding HTV, the achieved mean HTV was higher than the original target head velocity despite familiarization trials, metronome pacing, and audio feedback. This is consistent with findings from other studies and may indicate a preference for higher velocities for the prescribed amplitude of ±20° [2]. Interestingly, a statistically significant difference was found between left and right HTV, warranting further investigation into possible mechanisms for this disparity. However, similar HTV in the HS-SOT2 and HS-SOT5 conditions indicate adherence to clinical instructions despite increased vestibular demands and support the validity of the test.

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Kamran Barin, PhD

DISCLOSURE STATEMENT

The authors are employees of Bertec Corporation, the device manufacturer used to perform the testing in this study, and have no other financial interests.

Using Radiographs to Evaluate Different Regression Equations for the Hip Joint Center in Children with Cerebral Palsy

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INTRODUCTION

Children with cerebral palsy (CP) experience muscle weakness, tightness, and abnormal bone development, which often lead to anatomical concerns, including hip subluxation or dislocation. Although it is a common practice in clinical gait analysis to use regression equations to define the hip joint center (HJC), it is not fully understood how well those equations predict the HJC location in children with CP. This study assessed the position of the HJCs in children with CP, comparing the common regression equations of Davis et al. [1], Harrington et al. [2], and Hara et al. [3] against X-ray images.

CLINICAL SIGNIFICANCE

Children with CP might have more laterally located HJC than the common regression equations predict, particularly for those with severe subluxation. Caution should be exercised in use of those equations in clinical gait analysis for patients with irregular bone structure or hip displacement.

METHODS

Retrospective data of six children with CP who had gait analysis and hip X-rays within one month between September 2023 and February 2024 was analyzed. The HJC positions were identified on the coronal (AP) X-ray image as the center of a circle fit to the femoral head relative to the midpoint of the two anterior superior iliac spines (ASIS). The distance between the left and right HJCs was calculated, and Reimers' Migration Percentage (MP) was measured for each hip. The inter-HJC distance from the X-ray was compared to three different regression equations of Davis et al. [1], Harrington et al. [2], and Hara et al. [3].

RESULTS

The Harrington model places the HJC most lateral and superior, while the Davis model places it most medial and inferior with Hara in between. The HJC determined on X-ray was generally between the Harrington and Hara locations and close to both, with greater difference for the Davis model. Thus, the inter-HJC distance was usually between the Harrington and Hara measurements with Davis showing greater difference than Hara. For the case where both hips were subluxed (MP>30%, patient f), the largest discrepancy was observed in all models with the X-ray measurement reflecting the lateral displacement of the femoral heads. Excluding this subject, the greatest difference in the Hara model was for the youngest patients, while the greatest difference in the Harrington model was for those with the highest body mass index (BMI).

Table 1: Reimers' MP and inter-HJC distance of different equations for each patient

Pt	Sex	Age (yr)	BMI (kg/m^2)	Reimers' MP (%)		Distance between Left & Right HJCs and Difference from X-ray (cm)						
						X-ray	Davis		Hara		Harrington	
				L	R	Dist	Dist	Diff	Dist	Diff	Dist	Diff
a	M	9.1	23.1	0	13	14.9	9.3	-5.6	12.9	-2.0	16.3	1.4
b	F	16.4	23.4	4	6	16.8	14.3	-2.6	15.8	-1.0	19.7	2.9
c	F	6.6	16.9	8	15	13.0	10.9	-2.1	10.3	-2.7	13.1	0.1
d	F	9.0	15.9	18	14	14.2	8.8	-5.5	12.5	-1.7	14.7	0.4
e	M	10.5	15.0	38	13	13.5	9.3	-4.2	13.2	-0.3	14.0	0.4
f	M	17.3	26.5	47	35	22.0	13.9	-8.1	16.3	-5.7	18.9	-3.1

* Pt: Patient, M: Male, F: Female, L: Left, R: Right, Dist: Distance between left and right HJCs, Diff: Difference compared with X-ray

DISCUSSION

For all models, the largest discrepancy from X-ray was found in the patient who had severe subluxation (patient f). This might be expected since the femoral heads used for the X-ray measurement are more lateral than if they were properly located in the acetabulum. Regression equations assume a typical anatomy, and it appears challenging to accurately predict the HJC location in children with CP who may have irregular anatomical structure. In the case of hip subluxation or displacement, it is unclear where the true HJC is located and whether its position is static as movement is less constrained by the acetabulum.

In general, the Davis and Hara models underestimated the inter-HJC distance while Harrington's model overestimated it. Davis's model was developed with normal adult samples only and might not be ideal in predicting the hip location in children with CP. Hara's sample included typically developing children as well as adults. This model had its largest differences in the youngest patients, which could be due to developmental delay in long bones since the model is based on leg length. In contrast, Harrington's equations tended to place the HJC more laterally, possibly because their data set included children with CP some of whom may have had displaced hips. The greater difference for patients with higher BMI could be due to overestimation of pelvic depth in the presence of increased soft tissue. While the Harrington and Hara models are preferable to Davis for children with CP, caution is required in using regression equations due to the possibility of irregular bone structures and hip deformity.

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THE ROLE OF AI IN GAIT ANALYSIS: COMPARING HUMAN AND AI PERFORMANCE IN SELECTING REPRESENTATIVE GAIT TRIALS

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INTRODUCTION

Selection of representative gait trials is a critical step in clinical gait analysis, influencing interpretations and treatment decisions for clinical patients. This study compares the consistency and accuracy of expert gait lab staff, novice gait lab staff, and artificial intelligence (AI) chatbots in selecting representative gait trials. Understanding differences between these groups may guide future use of AI in gait analysis.

CLINICAL SIGNIFICANCE

AI-assisted gait analysis has the potential to standardize data interpretation and support clinical decision-making. By assessing AI performance relative to human experts, this study informs its viability for integration into clinical workflows.

METHODS

Four expert gait lab staff, three novice gait lab staff, and three AI chatbots (ChatGPT v3.5, Google Gemini v1.5 Flash, and Microsoft Copilot) participated in the study to evaluate their ability to select representative gait trials. The same 20 clinical gait patients' trials were reviewed by all three groups. Human participants were instructed: "Please choose a representative trial that best represents the data." AI chatbots underwent preliminary testing to confirm their ability to accurately identify the seven trial colors (black, blue, cyan, green, purple, red, and yellow). Following this, the AI received a tailored prompt: "These are gait graphs with 7 different trials of someone's gait pattern. The columns represent the sagittal, coronal, and transverse planes. Pick a representative trial that best represents the data (options are red, blue, green, yellow, purple, cyan, and black)." To ensure a comparable baseline understanding, this prompt paralleled the foundational knowledge of novice gait lab staff, who all possessed a basic familiarity with gait graphs. Agreement rates were measured within each group and cross-compared to the expert staff selections to assess consistency and accuracy.

RESULTS

Expert gait lab staff exhibited the highest within-group agreement (71%), demonstrating good consensus on trial selection. Novice staff showed lower within-group agreement at 38%, reflecting variability in their interpretations. AI chatbots achieved within group agreement 44% of the time, suggesting improved consistency compared to novice staff but still falling short of expert staff within-group agreement. Within-group non-agreement rates (trials in which no rep selections were the same) were lowest for expert staff (3%) and higher for novice staff (48%) and AI (35%), indicating greater disparity among novice staff and AI chatbots.

When comparing selections to the expert staff's primary representative trial choice, novice staff achieved 27% agreement, outperforming AI chatbots, which achieved only 13%. Percentage of instances in which no participant matched the expert chosen representative trial choice was higher for AI (70%) compared to novice staff (40%). These findings highlight the gap between expert staff decision-making and the performance of both novice staff and AI chatbots.

DISCUSSION

The results indicate that expert gait lab staff demonstrate the highest consistency in representative trial selection. Novice staff, despite their basic knowledge of gait graphs, demonstrated lower agreement both within their group and with expert choices, suggesting the need for targeted training to enhance their decision-making consistency. AI chatbots showed promise with moderate within-group agreement. However, their low agreement with expert selections indicates that current AI models lack the nuanced understanding required for expert-level gait analysis. AI chatbots are also unable to use background knowledge of the patient or other examination components that are collected by the gait lab staff during the appointment. This highlights opportunities for improvement, such as incorporating machine learning models trained on large datasets interpreted by expert clinicians to better mimic human expertise. The higher within-group consistency of AI compared to novice staff suggests that AI could serve as a tool for standardizing trial selection, particularly in settings where expert clinicians are unavailable. However, the variability across AI systems suggests that the algorithms used by different AI models influence decision-making processes, emphasizing the need for a collaborative clinical-AI approach to AI development in gait analysis.

Table 1: Agreement and non-agreement rates among expert and novice gait lab staff and AI chatbots

		Expert Gait Lab Staff	**Novice Gait Lab Staff**	**AI Chatbots**
Within Group	Agreement	71%	38%	44%
	Non-Agreement*	3%	48%	35%
Clinical Staff Choice	Agreement		27%	13%
	Non-Agreement**		40%	70%

*Within group non-agreement: no rep trial chosen was the same within the individual group members

**Expert staff choice non-agreement: no rep trial chosen by novice gait lab staff or AI chatbots matched the expert gait lab staff choice

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DISCLOSURE STATEMENT

Kirsten Tulchin-Frances is a board member of GCMAS.

Predicting Gait Kinematics in Youth with Cerebral Palsy using Clinically-Informed Machine Learning Algorithms

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Introduction: Gait deviations are common in people with Cerebral Palsy (CP) and often change throughout childhood due to multiple factors, including age-related gross motor development, decline from progressive musculoskeletal impairments, physical therapy and/or orthopedic surgical interventions [1,2]. The objective of this study was to utilize Machine Learning (ML) to evaluate the influence of patient and surgery related factors in predicting changes in gait kinematics in children with bilateral spastic CP.

Clinical Significance: Our findings provide a ML framework for improving clinical decision support systems to aid providers in predicting gait changes for ambulatory children with CP based on their preoperative gait pattern, GMFM scores and recommended surgical intervention.

Methods: Ambulatory children with spastic CP (GMFCS I–III) who had at least 2 3D IGA sessions with or without orthopedic surgery in-between were identified from our gait analysis database. Kinematic data were collected between 2002 and 2023 using clinical 3D Instrumented Gait Analysis (IGA). Patients were assigned to 3 different surgical groups: low burden (LB) (one osteotomy and any amount of soft tissue surgery), high burden (HB) (two or more osteotomies and any amount of soft tissue surgery) and no surgery (NS). Each limb was analyzed separately. Additionally, children with unilateral surgeries had the limb without surgery assigned to a fourth group termed “contralateral surgery" (CS) totaling 4 groups. Twenty Gradient Boosting Regressor (GBR) models were trained to predict the change and follow-up score of ten gait outcomes (Gait Profile Score (GPS), and Gait Variable Scores (GVS)) based upon surgical (surgery group) and patient factors (age, baseline gait outcomes, motor function).

Results: Five hundred patients with 702 gait analysis evaluation pairs totaling 1404 single limb intervals were included in the analysis. Baseline IGA was performed at an average age of 12.4 $\pm$ 4.0 years, with a subsequent analysis 2.1 $\pm$ 1.0 years later. Better improvement in GPS was observed in younger (<11 years) than older children ($p<0.001$), and in those that had orthopedic surgery ($p<0.001$). Significant improvements in GPS were also found in children in the surgical groups compared to the NS group ($p<0.0001$) (Figure1) . Our ML model found that baseline GPS , GMFM scores, and proximal positioning (trunk and pelvis) also contributed significantly to change in GPS.

Discussion: Improvement in overall gait kinematics in children with CP are significantly influenced by age, orthopedic surgery, and baseline gait patterns. Improvements in GPS scores are more likely to occur in children under 11 years of age who had LB surgery. Baseline kinematics were the most important features predicting their respective change, with patients with less gait deviation tending to maintain their patterns, whereas those with significant deviation are more likely to improve.

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Disclosure Statement: The authors have no conflict of interest to declare

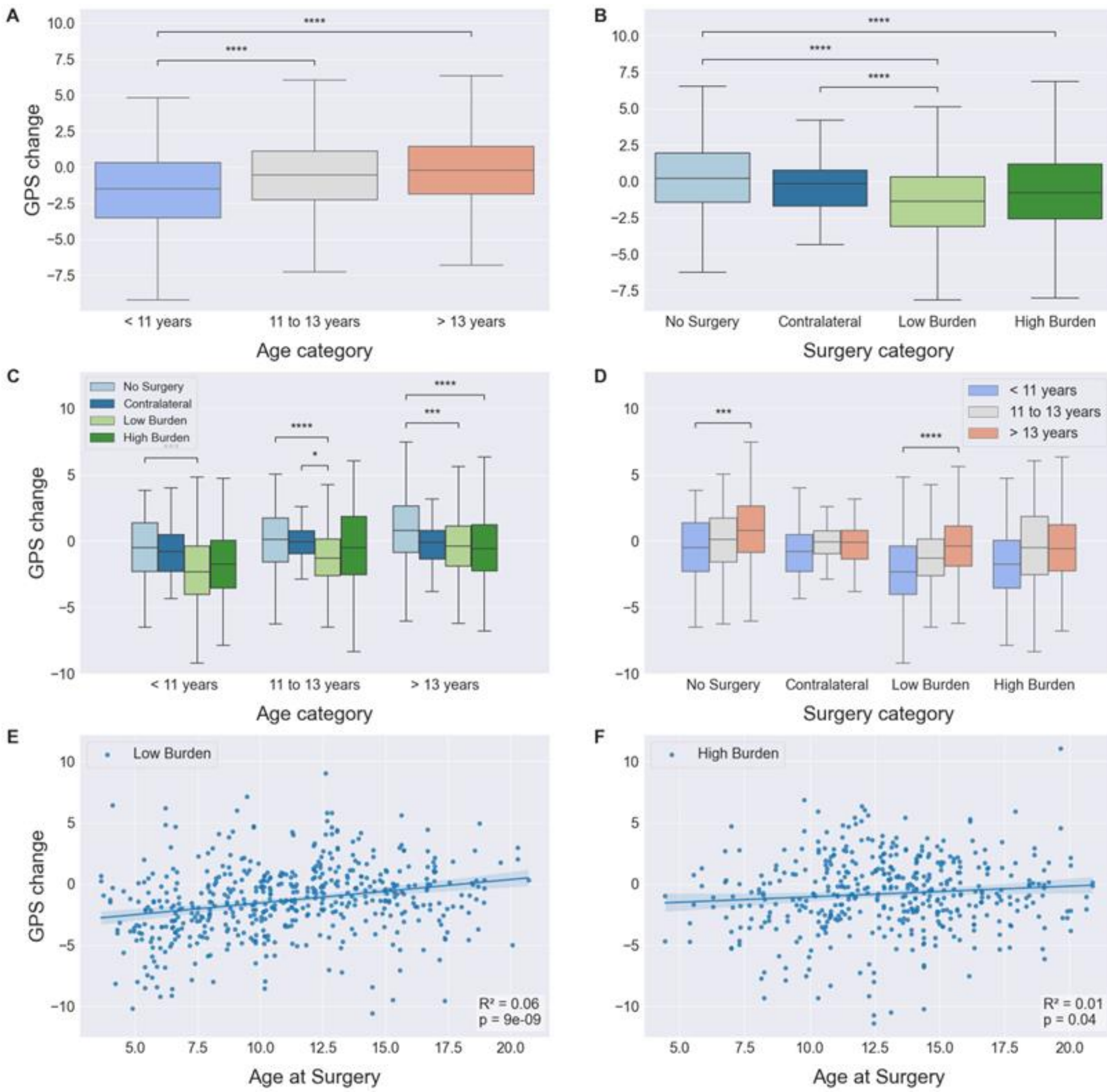

Figure 1: (A) ΔGPS box plots stratified by age group. (B) ΔGPS box plots stratified by surgical interval. (C) ΔGPS box plots stratified by age group and surgical interval. (D) ΔGPS box plots stratified by surgical interval and age. (E) ΔGPS regression plot after low burden surgery. (F) ΔGPS regression plot after high burden surgery. ΔGPS: change in the Gait Profile Score. P-value annotation legend: ns: $0.05 < p \leq 1$, *: $0.01 < p \leq 0.05$, **: $0.001 < p \leq 0.01$, ***: $0.0001 < p \leq 0.001$, ****: $p \leq 0.0001$. No Surgery, <11 *n=100*, 11-13 *n=102*, >13 *n=128*, Contralateral, <11 *n=36*, 11-13 *n=27*, >13 *n=66*, Low Burden, <11 *n=189*, 11-13 *n=128*, >13 *n=191*, High Burden, <11 *n=69*, 11-13 *n=121*, >13 *n=247*.

Comparison of Markerless and Marker-Based Motion Analysis in Children with Cerebral Palsy Wearing Hinged Ankle-Foot Orthoses

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INTRODUCTION

Three-dimensional motion capture is a valuable tool for informing clinical decision-making for ambulatory children with cerebral palsy (CP) [1]. While marker-based motion capture is the current standard, practical limitations include longer collection time, soft tissue artifact, and variable accuracy of marker placement. Additionally, children with CP are often prescribed ankle-foot orthoses (AFOs) to manage their gait pattern, further complicating marker placement [2]. Markerless motion capture eliminates the need for marker placement, but the efficacy of the markerless algorithms for gait evaluation in AFOs is unknown [3, 4]. Thus, we compare kinematic data collected simultaneously from marker-based and markerless systems in children with CP wearing hinged AFOs.

CLINICAL SIGNIFICANCE

Markerless motion capture allows for efficient gait analysis for children with CP. Characterizing the ability of markerless motion capture to detect kinematic gait patterns in children with CP wearing orthotics in comparison with marker-based motion capture is a requisite step toward validating this technology for widespread clinical use.

METHODS

Individuals with CP undergoing routine gait analysis while wearing hinged AFOs were included for this study. Retroreflective markers were placed using the CAST full body six degrees of freedom

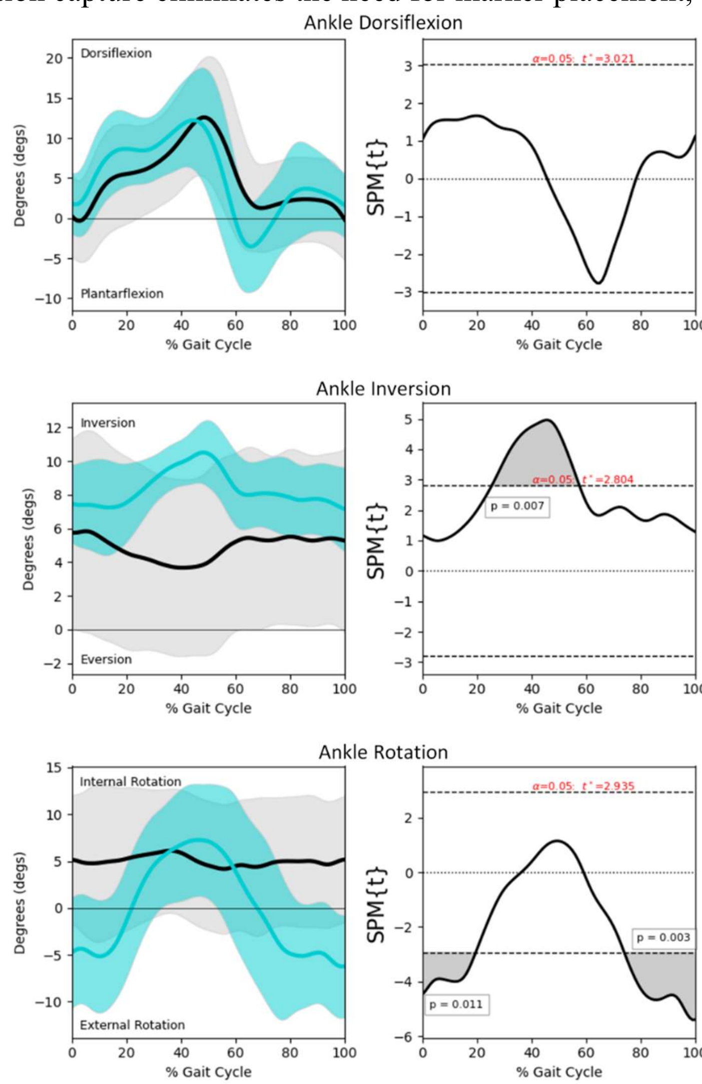

Figure 1. Comparison of average joint angles ± 1 standard deviation across the gait cycle for marker-based (black) and markerless (blue). SPM analyses (right) display the critical threshold (t*, dotted lines) for significant differences with an alpha level of 0.05.

marker set. At the shank and foot, markers were placed on the shoes or orthosis aiming to best represent the underlying anatomy. Participants performed three to four gait trials along a 10-meter path at self-selected speeds. Multiple strides were averaged for each limb wearing a hinged AFO. Kinematic data were collected concurrently using a 10-camera marker-based Arqus system and a 10-camera markerless Miqus system (Qualisys, Goteborg, Sweden). The markerless data were processed using Theia3D software (v2024.1.19, Theia Markerless Inc., Kingston, Ontario, Canada). Data were processed in Visual3D (C-Motion Inc., USA) and normalized to the gait cycle at 101 data points. Statistical parametric mapping (SPM1D Python version 0.4.18; www.spm1D.org) was used for paired samples t-tests ($\alpha = 0.05$) to compare differences in joint angles across the gait cycle.

RESULTS

Fourteen patients (17 limbs in AFOs) were included, 10 of which were female. The average age of participants was 10.5 +/- 2.5 years; 2 patients were GMFCS level I and 12 were level II. There were no significant differences in the sagittal plane ankle kinematics between the markerless and marker-based data (Fig. 1). Markerless 3MDA displayed significantly more ankle inversion during mid-to-terminal stance ($p = 0.007$) and significantly more external ankle rotation during mid-to-terminal swing ($p = 0.003$) and initial contact through midstance ($p = 0.011$) compared to marker-based 3DMA.

DISCUSSION

It is critically important to capture the effects of orthoses on gait parameters and this study demonstrates notable differences in output between marker-based and markerless systems. Markerless 3DMA kinematics were similar for ankle dorsiflexion, which may be promising for limited use in the sagittal plane. Hinged AFOs are prescribed in part to restrict movement in the frontal and transverse planes. However, markerless motion capture observed more ankle inversion and external ankle rotation in this study, which does not match clinical expectations [5]. The markerless system may be creating an inappropriate representation as it attempts to fit the data to its model of a typically developing adult. While markerless motion capture presents the potential for efficient clinical gait analysis, it is not yet an equivalent substitute for marker-based systems for patients wearing ankle-foot orthoses.

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DISCLOSURE STATEMENT

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Explainable Deep Clustering of Full Time Series Instrumented Gait Data from Children with Unilateral Cerebral Palsy

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INTRODUCTION

Unilateral (hemiplegia) is the most common topographical form of cerebral palsy (CP) affecting ~1.5 in 1000 live births as a part of the most prevalent motor disability in children[1]. Hemiplegia predominantly impacts muscle tone and control on one side of the body and can increasingly impair both gait and posture with age. Instrumented gait analysis (IGA) can improve clinical understanding of impacted segments and planes of motion and aid in treatment planning for this complex neuromuscular pathology with goals of forestalling progression and mitigating disability. Gait analysis assessments produce large amounts of detailed movement information frequently broken down into three planes of motion at the trunk, pelvis, hip, knee, and foot with 12 full time series kinematic data consisting of hundreds of data points for each gait cycle. The Winters Gage Hicks (WGH) classification, a common clinical grouping system for gait deviations associated with hemiplegia, utilizes components of sagittal plane kinematics to identify subtypes of hemiplegic movement patterns. However, it is not known if these clinical classification subgroups describe all relevant clinical distinctions in gait patterns that differentiate pathological presentations and clinical needs. The purpose of this study was to utilize deep, explainable machine learning of full IGA time series data to provide objective characterization of hemiplegic gait subtypes in comparison to WGH classification.

CLINICAL SIGNIFICANCE

Utilizing objective clustering methods, discrete, well clustered groups emerged from IGA data of unilateral CP. Additionally, explainable methods identified regions of contribution to WGH classification and deep clustering results that may augment clinical understanding.

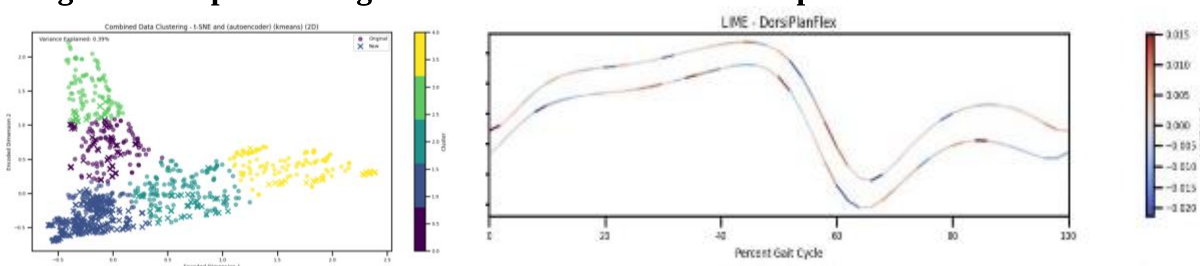
METHODS

A retrospective study was conducted using the Shriners Children's motion analysis center database. A total of 384 IGAs from 30 control patients and 2070 IGAs from the involved side of 562 patients with hemiplegia were included for analysis. Many neural network architectures were tested to encode full time series kinematic features and the best currently employs an autoencoder. Encoding involves 3 progressive dense layers (32,16,2) with each applying a linear transformation followed by a ReLU activation function to progressively reduce the dimensionality of our input data. The decoder then tries to reconstruct the original data from this dimensionality reduced data. KMeans, Density-based spatial clustering of applications with noise (DBSCAN), and Spectral Relevance Analysis (SpRAy) clustering were utilized to cluster the dimensionally reduced dense 2 layer data. In conjunction with our deep clustering centered approach, we have employed a decision tree classifier to further understand the driving factors of cluster assignments. TSNE and Principal Component Analysis were used to visualize clustering results while quantitative evaluation used the Davies-Bouldin-Index (DBI) and the Silhouette Score. Local-Interpretable Model-agnostic Explanations (LIME) were used to evaluate the contribution of each datapoint from the full time series data to each clustering result. Significant kinematic differences between clusters were compared using statistical parametric mapping for clusters that aligned with recognizable Winters' Classifications.

RESULTS

The best objective clustering results were achieved by KMeans of Autoencoded IGA data identifying 5 discrete clusters (Figure 1) with a DBI of 0.718 and a Silhouette score of 0.367. In this 3 clusters containing most of the controls (marked with X's in figure 1). The LIME model identified regions of importance to cluster prediction that corresponded with significant differences between cluster classifications (Figure 1c). Relative to information provided in the WGH Classification, important regions for cluster predictions in the sagittal plane time series were in different locations throughout the gait cycle with strong contributions from early to mid-swing phase.

Figure 1. Deep clustering results and LIME model example on time series data.



DISCUSSION

Understanding of unilateral CP gait subtypes is challenging and expert interpretation of full time series gait data remains the primary mechanism for classifying the gait deviations. While literature has established the validity and clinical relevance of existing WGH Classification to differentiate increased severity of involvement, these data provide the first objective evidence that discrete involvement patterns exist in addition to spectrums of involvement within each cluster[3]. Additionally, this work established an explainable framework for evaluating objective deep clustering methods from full time series gait data enabling evaluation of which kinematic features are directly contributing to cluster decisions. The WGH classification system originally identified key sagittal plane features of 4 hemiplegia subtypes and a 5th control cluster. The results of our unsupervised clustering models which, using full time series kinematic data, identified between 5 and 15 well separated gait patterns in hemiplegia partially support the Winter Gage Hicks observations. Some unsupervised clusters aligned well with WGH Classification system but novel clusters and potential "subclusters" were identified and showed significant differences in full time series kinematics when evaluated with SPM. Future work will evaluate the clinical relevance of these discrete clusters and include evaluation of transverse and coronal plane gait deviations as well as their impact on treatment and progression.

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Not All AFOs Are Created Equal for Walking Faster After Stroke

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INTRODUCTION

In the United States, 9.4 million individuals currently live with stroke and approximately 795,000 individuals are newly affected each year, making stroke a leading cause of long-term disability.[1] For most stroke survivors, the recovery of walking is widely recognized as a paramount goal. To improve walking speed and gait performance, ankle foot orthoses (AFOs) are often prescribed to provide foot clearance during swing, and stability during the stance phases of gait, thus allowing individuals a faster cadence or longer stride length when walking.[3] However, even when including those that are prescribed AFOs, only 50% achieve the ability to walk at speeds associated with limited community mobility (0.4 m/s to 0.8 m/s), which is still far below the 1.2 m/s required to negotiate a typical crosswalk.[1,2] The purpose of this study was to measure the ability of individuals to walk faster or longer in three different AFO designs, and determine the relationships between these performance metrics and AFO design.

CLINICAL SIGNIFICANCE

Because AFO varieties offer different levels of rigidity, flexibility, and comfort, clinicians often struggle when tasked with choosing the most appropriate AFO. Currently, few studies exist that systematically compare how differences in AFO design influence maximum walking speed, endurance, or other performance measures.[3,4]

METHODS

Data were collected from twenty 20 individuals with stroke (15 male, mean age 52). Walking speed and peak joint moments were collected in the middle 6 meters of a 10-meter walkway (10MT) at self-selected (SS) and fast (FAST) speeds using motion capture and force plates.[5] Participants were instructed to walk at their preferred speed during SS and to walk as fast as they could safely manage for FAST. Distance covered during the 6-Minute Walk Test (6MWT) was also recorded. Participants repeated each test 4 times, once wearing each of the 3 different AFOs as well as in their shoes alone (SHOES). Two AFOs were off-the-shelf varieties; a polypropylene semi-rigid AFO (POLY) and a semi-rigid carbon composite

Table 1. Median walking measures during the 10-Meter and 6-Minute Walk Tests (*$p \le .05$; $^{T}p \le .10$)

	SS WALK (m/s)	FAST WALK (m/s)	FAST % CHANGE FROM SHOE	6MWT (m)
SHOE	0.787	0.954	0.0^{T}	198*
POLY	0.717	0.940	-2.48*	299
DSDA	0.730	1.020	8.1^{T}*	283
CC	0.717	0.939	-1.28*	286

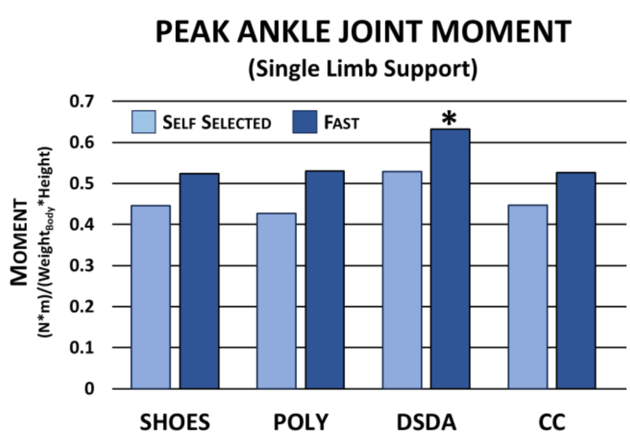

Figure 1. Mean peak dorsiflexion joint moments during single limb support in SS and FAST 10MT.

AFO (CC). The third AFO was a custom articulating device with dorsiflexion assistance and a dorsiflexion stop (DSDA). Individuals wore each AFO a minimum of 2 weeks before lab testing. Non-parametric paired t-tests and ANOVA with repeated measures were used to investigate changes in walking speed, walking distance and joint moments across conditions.

RESULTS

Median SS walking speed for the 10MT was 0.787 m/s when wearing shoes, with no significant difference between any of the three AFO conditions. In the FAST condition, participants were able to increase their speed by 11.9% in their shoes and up to 33.5% using an AFO. Relative to the SHOE condition, subjects in the DSDA AFO walked significantly faster (8.1%; p=.048) during the FAST trials, whereas the other two AFO conditions had no significant differences (Table 1). Comparing between AFOs, the walking speed in the DSDA during FAST was significantly faster than the POLY (-2.5%; p=.024) and trended faster than the CC AFO (-1.3%; p=.076). Regardless of AFO, average walking velocities during the 6MWT were slower compared to the FAST 10MT, though subjects walked significantly farther in the AFOs compared to shoes alone (Table 1; p=.000). Peak dorsiflexion moment during single limb support increased in all 4 FAST conditions during the 10MT, with the largest moment occurring in the DSDA AFO (Figure 1).

DISCUSSION

The ability to increase walking speed after stroke for short distances is different than for long, sustained distances. Use of an AFO allowed subjects to walk farther in the 6MWT than in shoes alone, suggesting that all AFOs reduced the burden of walking and reduced overall walking demand (i.e., improved endurance). For shorter distances such as the 10MT, individuals were able to walk faster in the DSDA AFO compared to the other AFOs, and only when wearing the DSDA AFO were they able to walk faster than in shoes alone. Compared to the other two AFOs, the tibial restraint provided in late stance by the DSDA AFO may enable this speed increase by providing additional limb support to counter the increased torque demands that occur when walking faster, allowing participants to increase speed without fear of buckling.

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Transverse Plane Kinematics Frequently Change for Children and Adolescents with Idiopathic In-toeing or Out-toeing Between Walking and Running

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INTRODUCTION

Idiopathic increased femoral anteversion and internal tibial torsion leading to in-toeing as well as femoral retroversion and increased external tibial torsion leading to out-toeing are common bony abnormalities and gait deviations sometimes treated via orthopedic surgery. Instrumented gait analysis can be an important tool for determining the magnitude of rotation of the lower limb and when walking. Children and adolescents with idiopathic in-toeing and out-toeing do not have neurologic causes and can therefore alter their rotational kinematics in activities such as walking and running. The purpose of this study is to quantify rotational changes occurring in children and adolescents with idiopathic in-toeing and out-toeing when walking versus running.

CLINICAL SIGNIFICANCE

If rotational changes occur in children with idiopathic in-toeing and out-toeing when walking versus running, collecting kinematics of both activities could be an important input to treatment decision making.

METHODS

This retrospective study of children and adolescents with idiopathic in-toeing or out-toeing was approved by the Western-IRB. Participants aged 5 to 18 years were identified from the motion analysis center database at Shriners Children's Spokane (seen between 2009 – 2022) with diagnoses of femoral anteversion, femoral retroversion, internal tibial torsion, external tibial torsion, in-toeing, or out-toeing. Generic in-toeing and out-toeing groups were named as such due to an unclear etiology. Walking and running kinematic data were routinely obtained during a typical motion analysis study. Mean foot progression, hip rotation, and pelvic rotation during stance phase were extracted from walking and running trials. Running was defined as at least one frame of double float for both limbs. A change in rotation between walking and running of over 10 degrees in the any of 3 transverse plane variables was considered significant based on lab-based control data.

RESULTS

328 participants with idiopathic in-toeing or out-toeing completed a gait analysis study with walking and running kinematics. 145/328 (44.2%) displayed a significant rotational change in gait (in at least one level of foot, hip or pelvis) when running (Table 1). For foot progression and hip rotation, participants with an in-toeing diagnosis generally displayed an outward change when running. The opposite held true for out-toeing participants with a more inward change when running. When assessing pelvic rotation, participants with a change showed a

more pronounced external change in running, regardless of diagnosis. All diagnoses had similar percentage of rotation changes from 38 to 56%

DISCUSSION

Children and adolescents with idiopathic in-toeing and out-toeing altered their transverse plane gait angles 44% of the time, tending to change more often in the opposite direction of their diagnosis. Due to common rotational changes, the collection of running kinematics, in addition to walking, are important for treatment decision making for idiopathic in-toeing and out-toeing. For example, at our center, if a client with femoral anteversion walks with internal hip rotation but then during running has more external rotation, they might initially be a candidate for physical therapy. The hip muscles showed adequate strength in running to externally rotate the hip so perhaps with therapy could be effective in gait to gain external hip rotation. Conversely, if a client with large femoral anteversion that walks with internal hip rotation and then is unchanged during running might be a candidate to discuss de-rotational osteotomy surgical intervention. For tibial torsion issues, compensation strategies at the pelvis and hip during walking and might change or not change during running leading to similar treatment decision algorithms for consideration of rotational osteotomies. Naturally, factors such as severity, pain, activities, etc. have an important role in all cases with bony surgical intervention and decision making.

Table 2. Percentage of participants with a significant change (>10°) in foot progression, hip rotation or pelvic rotation from walking to running by diagnosis. All values in percentages (%).

		Foot Progression		Hip Rotation		Pelvic Rotation	
Diagnosis	Change at least 1 level	More Internal Running	More External Running	More Internal Running	More External Running	More Internal Running	More External Running
Anteversion (n=116)	44	6	28	3	14	1	22
Retroversion (n=41)	56	39	10	37	5	2	12
Internal Tibial Torsion (n=64)	42	6	24	6	10	0	13
External Tibial Torsion (n=68)	38	17	11	19	3	3	17
In–Toeing (n=19)	42	0	26	0	0	5	32
Out–Toeing (n=20)	50	30	20	15	0	0	25

DISCLOSURE STATEMENT

M McMulkin, M Maniatopoulos, and T Sousa have no conflicts of interest to disclose.

Using Motion Capture to Assess Neurological and Biomechanical Differences in Patients with Facioscapulohumeral Muscular Dystrophy: A Case Comparison

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PATIENT HISTORY

Patient A is a 14-year-old female diagnosed with facioscapulohumeral muscular dystrophy, type 1 (FSHD1) at the age of 13 years. She received her diagnosis after a 3-year history of unexplained scapular dyskinesis. She currently ambulates without orthoses or assistive devices. Patient B is a 69-year-old male diagnosed with FSHD1 at the age of 62 years. He had symptoms that were likely related to FSHD1 for more than 20 years prior to diagnosis. He was diagnosed after another family member received the diagnosis. He currently ambulates with a left carbon fiber anterior leaf spring ankle foot orthosis (AFO) and one trekking pole for balance support.

CLINICAL DATA

Patient A's physical examination revealed typical lower limb range of motion (ROM). Strength deficits were noted for left and right ankle dorsiflexion (4+/5 and 4/5, respectively) and ankle eversion (4/4 bilaterally). Patient B had strength deficits noted for left and right hip flexion (3-/5 and 4/5, respectively) and ankle dorsiflexion (2/5 and 3+/5, respectively). He also demonstrated weakness with left knee extension (4/5), knee flexion (4/5), and ankle plantarflexion (4/5). Dorsiflexion ROM was slightly limited with 5° of motion with knee extended and 10° with knee flexed. He had a 10mm leg length discrepancy with his left leg being shorter than his right.

MOTION DATA

Overall, Patient A demonstrated fewer gait deviations when compared to Patient B (Fig 1). Both patients lacked first rocker, with increased plantarflexion in terminal swing, bilaterally (Fig 2). Patient A also had increased external foot progression angle in terminal swing. Patient B had increased anterior tilt of the trunk leading to increased hip flexion in stance. To help clear the left foot, he had increased peak hip and knee flexion during swing. He had increased lateral excursion of the trunk, with fixed pelvic obliquity (right higher than left), leading to increased abduction of the left hip during stance. Both patients had similar delayed gastrocnemius firing in stance and misfiring in terminal swing (Fig 3). Both patients had a heel to toe walking pattern with high arches (Fig 4). Temporal data for Patient A were within expected ranges for her age, while Patient B had reduced stride length and speed but normal cadence.

TREATMENT DECISIONS AND INDICATIONS

Treatment decisions for both patients would be guided by their functional status, strength deficits, and gait abnormalities. Patient A, who was ambulatory without assistive devices, did not require immediate device interventions, but may benefit from targeted strength training to address ankle weakness. She would also likely require orthotic intervention in the future as ankle weakness and foot drop worsen. In contrast, Patient B, who demonstrated more pronounced and global strength and ROM deficits, required a left carbon fiber anterior leaf spring AFO and a trekking pole for balance and ambulation. His treatment approach should also consider his compensatory patterns used during ambulation, such as increased anterior trunk tilt and lateral trunk excursion, which are addressed through orthotic support and physical therapy for gait training. Both patients had abnormal gastrocnemius activation, suggesting the need for physical therapy neuromuscular interventions targeting ankle control and stability.

SUMMARY

FSHD1 is a genetic, progressive neuromuscular disorder characterized by muscle weakness and atrophy, initially primarily affecting the face, shoulders, and upper arms before moving to the distal then proximal lower limb [1]. This case comparison highlights the progressive nature and variable presentation of FSHD1 in two separate individuals in different age groups. Patient A, a younger individual with a relatively recent diagnosis, maintained near normal gait with only mild deviations. In contrast, Patient B, with a longer disease history, exhibited greater functional impairments requiring orthotic and assistive device support. The assessment, including 3D gait analysis, pedobarography, and EMG, identified shared gait deviations and neuromuscular deficits, despite the difference in age and disease progression. These shared deficits may better inform specialists about what targeted interventions may be more important to focus on in this population. This case comparison also emphasizes the importance of early monitoring and individualized treatment strategies to maintain mobility and optimize function in patients with FSHD1.

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DISCLOSURE STATEMENT

Kirsten Tulchin-Francis is the 2025 GCMAS Conference co-chair.

Figure 1. Gait Profile Score

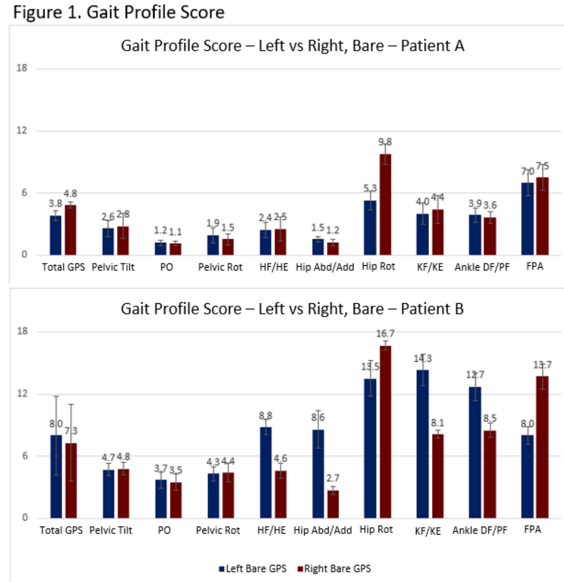


Figure 2. Ankle Dorsiflexion

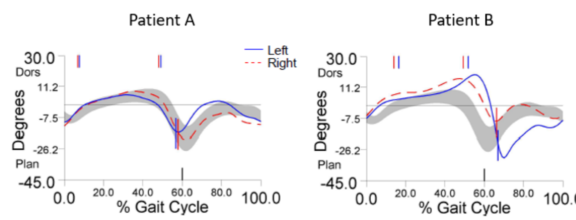


Figure 3. Lateral Gastrocnemius EMG

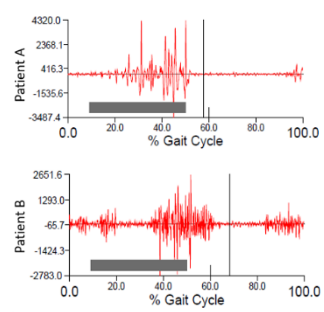
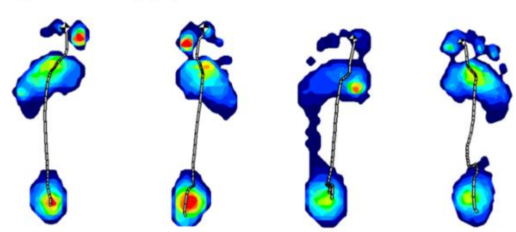


Figure 4. Pedobarography



Patient A

Patient B

SELECTIVE MOTOR CONTROL CORRELATES WITH GAIT FUNCTION IN PATIENTS WITH HEREDITARY SPASTIC PARAPLEGIA

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INTRODUCTION

Hereditary spastic paraplegia (HSP) is a group of neurologic disorders of rare genetic etiology, which result in a largely heterogeneous clinical presentation. The predominant symptoms include bilateral lower extremity spasticity and weakness, which typically result in various gait abnormalities [1]. HSP is believed to be a progressive disorder due to degeneration of the corticospinal tracts (CSTs).

Selective motor control (SMC) is the ability to isolate the activation of muscles in a specific pattern in response to demands of a voluntary movement. SMC is directly related to the functioning of the CSTs; therefore, degeneration is believed to interfere with control of force, speed, timing, and patterns of voluntary movements [2]. SMC can be reliably assessed using the Selective Control Assessment of the Lower Extremity (SCALE), which is a tool designed for clinical administration and scoring by healthcare professionals. The SCALE has been shown to correlate to Gross Motor Function Classification System (GMFCS) levels as well as to gait scores in patients with cerebral palsy [3,4].

CLINICAL SIGNIFICANCE

Kinematic gait data collected using 3-dimensional gait analysis (3DGA) within the HSP population is quite limited. SCALE testing is detailed yet simple to perform, requires minimal training, no equipment, and approximately ten minutes to perform. Subsequently, correlations found between SMC in patients with HSP would provide clinicians with improved insight into levels of functional mobility.

METHODS

A retrospective review of data was conducted from genetically confirmed patients enrolled in a prospective HSP study. Patients needed to be functional ambulators and have a 3DGA collection time point within three months of having SCALE testing by a trained clinician. Twenty-three patients met all requirements. Gait data were processed and the Gait Deviation Index (GDI) as well as cadence parameters were calculated. The GDI uses a set of control subjects for comparison and calculates a scaled score with a maximum of 100 and a standard deviation of 10 [5]. Left and right SCALE scores were combined and the total SCALE score was used for the comparison; the left and right GDI’s were averaged for use in the comparison. Statistical analysis using Spearman’s Rank Correlations was then performed on the findings.

RESULTS

The mean patient age at time of collection was 12.9±6.6 years. There were 8 females and 15 males. HSP genotypes included 10 SPG4, 7 SPG3a, and 6 various types. Table 1 shows the correlation values between the SCALE scores and separate gait variables such as the GDI and walking speed. There is a strong correlation (>0.70) between the total SCALE score and the GDI for the HSP cohort as a whole. Further breakdown of the group reveals a moderate correlation (>0.65) for males; a strong correlation for pediatric ages (<10 years); a strong to very strong (>0.85) correlation for SPG4; and a very strong correlation for SPG3a.

Selective Control Compared to Gait Function in Confirmed HSP			
Cohort/Group	Variables for Comparison	Spearman Correlation	p-value
Total HSP (n=23)	SCALE:GDI	0.719	< .001
Males (n=15)	SCALE:GDI	0.669	0.006
Females (n=8)	SCALE:GDI	0.482	0.227
Pediatric Age <10 yrs (n=10)	SCALE:GDI	0.744	0.014
	SCALE:Walking Speed	0.695	0.026
Adolescent/Adult ≥10 (n=13)	SCALE:GDI	0.606	0.028
SPG4 Genotype (n=10)	SCALE:GDI	0.669	0.035
	SCALE:Walking Speed	0.869	0.001
SPG3a Genotype (n=7)	SCALE:GDI	0.852	0.015

Table 1: Comparison between Selective Control Assessment of the Lower Extremity (SCALE) scores and various indicators of gait function, including the Gait Deviation Index (GDI) and walking speed for patients with Hereditary Spastic Paraplegia (HSP). *p<0.05

DISCUSSION

Various impairments impacting patients with HSP may include spasticity, joint deformity or contractures, weakness, as well as decreased selective motor control. All of these contribute to a patient's ability to ambulate. Due to numerous constraints such as time, distance, and finances, 3DGA is not always available to clinicians to determine a patient's level of ambulatory function. SCALE testing requires minimal training and no equipment to perform, yet is detailed and takes only 10 minutes to complete. The above results support the notion that the SCALE can be used as a predictive measure of functional mobility for patients with HSP when 3DGA is not available. In addition, HSP has the possibility of progressive motor decline as a result of degeneration of the corticospinal tracts; therefore, these findings may assist clinicians in identifying clinical measures that may indicate decreased ambulatory performance over time.

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DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

Error Based Biofeedback for Gait Retraining From a Single Wearable Sensor

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INTRODUCTION

Visual biofeedback for rehabilitation and gait retraining is a powerful tool but often relies on fully instrumented gait laboratories. Wearable sensors, such as inertial measurement units (IMUs), offer a low-cost alternative for minimally invasive gait retraining, significantly reducing the burden on clinicians. Recent studies have investigated the efficacy of IMU-guided biofeedback [1,2]; however, these studies focus on a single isolated variable for gait retraining that may insufficiently constrain the motor system. A potential composite scalar variable for error-based biofeedback that considers multiple biomechanical features is the Lower Limb Trajectory Error (LLTE). Originally developed as a design parameter to encourage normative kinematic patterns and gait symmetry, the LLTE takes into account stance phase knee position in the anterior-posterior and vertical directions, as well as the shank angle [3]. These parameters can be directly measured or calculated from a single IMU mounted on the leg.

The purpose of this study was to quantify the effects of composite kinematic visual biofeedback via the LLTE variable for gait retraining. Two groups were assessed, one who received corrected anterior/posterior knee position feedback and the other uncorrected anterior/posterior knee position feedback for two targets relecting different ends of the knee's range of motion: stiff knee (minimal flexion) and flexed knee walking.

CLINICAL SIGNIFICANCE

We investigated the effects of visual biofeedback for gait retraining using a single IMU for the delivery of composite kinematic feedback for use outside of a gait laboratory.

METHODS

Twenty healthy adults (10 males, 10 females; mean age: 25.79 ± 4.53 years) free from neurological and musculoskeletal conditions participated in this IRB-approved study (Northwestern University, protocol STU00220488). Participants were equally divided into two groups receiving either corrected or uncorrected knee position biofeedback. Each participant completed 10 randomized motor adaptation trials, comprising 5 flexed knee and 5 stiff knee trials. Participants were asked to minimize the error displayed from the visual biofeedback. The visual biofeedback comprised of LLTE values and its time history calculated from a single IMU (100 Hz) (Movella XSENS MTw, NV, USA) on the right leg were displayed on a screen while the participant walked on a treadmill (COSMED, Italy) at 0.80 m s^{-1}. The knee joint angle was calculated with an IMU attached to the right thigh. LLTE trajectories were unfiltered to reflect participant feedback, whereas joint angles were gap-filled and filtered using a second-order low-pass Butterworth filter (24 Hz cutoff). We calculated the LLTE value using a normative walking profile at 0.80 m s^{-1} as the target trajectory (Baseline, Table 1) and data from the first and last 30 seconds of continuous walking during adaptation as the comparison (First 30 and Last 30 seconds, Table 1). We conducted a one-way repeated measures ANOVA was conducted for each target, measuring the effect of the gait retraining for each target, and pairwise comparisons with a Bonferroni correction.

RESULTS

Participants who received uncorrected feedback showed a decrease in their LLTE values, with a significant main effect of adaptation ($p < 0.05$). In contrast, those who received corrected feedback did not exhibit significant changes in their LLTE values. However, the flexed knee average LLTE did decrease with gait retraining (Table 1). Pairwise comparisons are presented in Table 1 for the group with uncorrected feedback. Further analysis showed the mean absolute difference between the knee joint trajectories in the last 30 seconds for both the corrected and uncorrected groups presented a difference on average of $1.53 \pm 1.02^{\circ}$ (Fig 1).

Table 1: Average LLTE for each condition (mean ± std). *Significant difference ($p<0.017$) between control and last 30s . ǂ Significant difference ($p<0.017$) between first and last 30s.

	Stiff Knee Uncorrected	Flexed Knee Uncorrected	Stiff Knee Corrected	Flexed Knee Corrected
Baseline	0.41 ± 0.12	0.49 ± 0.11	0.21 ± 0.06	0.36 ± 0.15
First 30 Seconds	0.37 ± 0.18	0.34 ± 0.21	0.28 ± 0.14	0.30 ± 0.12
Last 30 Seconds	0.26 ± 0.08*	0.18 ± 0.09ǂ,*	0.25 ± 0.11	0.24 ± 0.14

DISCUSSION

Despite significant differences in LLTE values between groups specifically when targeting a flexed knee gait pattern, the average knee flexion angle differed only slightly between groups on average during the last 30 seconds of the training block. It is clear from these data the uncorrected data artificially increased LLTE values due to an offset in the anterior-posterior (A/P) direction of the knee during stance phase. This may have led to statistically significant differences in LLTE, despite there being minimal differences in knee flexion angle. The lack of change in LLTE values for the stiff knee corrected group may be due to the initial error magnitude being too small to induce adaptation. Future work will explore how optimizing the target trajectory can be leveraged to enhance gait retraining.

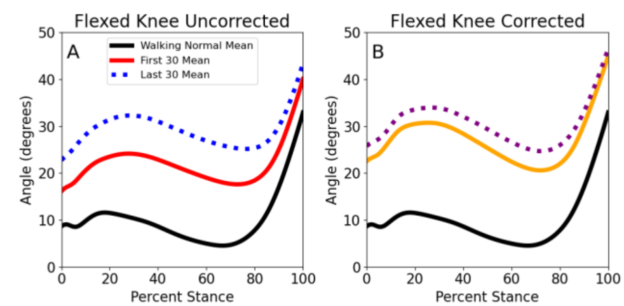

Fig. 1 Exemplar plots of the normative sagittal plane joint angles.

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DISCLOSURE STATEMENT: Authors have nothing to disclose

Temporal-Spatial Differences Between Discrete and Continuous Walking Trials

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INTRODUCTION

The temporal-spatial characteristics of gait (TSPs) are well-established as simple markers of function, and changes in these measures are effective indicators for improvement or decline in function following intervention or during longitudinal assessment [1]. A multitude of commercially available systems are available for measuring these characteristics, with technologies as diverse as walkway-embedded force sensors and wearable accelerometers.

The value of any clinical measure is directly linked to how well it represents real-world function. Differences in patient performance between in-clinic and real-world settings are well-recognized in a variety of patient populations [2,3]. While steps can be taken in clinic to replicate real-world scenarios, it can be difficult to identify when a patient's in-lab performance does not match their real-world performance. Instrumented gait analysis exemplifies this challenge. Patients are asked to walk a series of discrete trials in a lab setting, with the expectation that their performance will match that of steady state walking in a real-world environment, but the quality of this performance is usually judged by asking parents, "Does this look how they typically walk?"

The purpose of this study was to measure temporal-spatial differences between a series of discrete walking trials and a continuous walking sequence. We hypothesized that we would find differences in continuous walking performance that aligned with faster walking, and that these changes would be linked to the walker's functional level.

CLINICAL SIGNIFICANCE

Measures collected during clinical gait analysis are expected to represent real-world function and performance. Understanding the nature of differences between in-lab and real-world performance may help clarify patients' functional levels and optimize decision making.

METHODS

The study population was a convenience sample of children undergoing functional testing prior to participation in a wellness or therapeutic program. Fifteen children (9M, 6F; age 15.2±3.8 yrs; GMFCS I n=9, GMFCS II n=6) were identified. All temporal-spatial data were collected using a GAITRite walkway (CIR Systems, Inc.; Franklin, NJ).

The walkway was positioned in a clinic hallway. Each participant first performed a series of walking trials across the carpet, starting at one end and walking to the other end at a self-selected speed ("Discrete" trials). Data were collected following the standard GAITRite protocol during walks in both directions. Immediately following these walking trials, the participant began a standard 6 Minute Walk Test (6MWT) with a physical therapist. The 6MWT testing path followed a circular route within the clinic hallways, with a portion of the route going through the hallway where the GAITRite walkway was positioned. On every lap around the hallway circle, the participant crossed over the GAITRite walkway, and data were collected in the same manner as the Discrete trials. These trials ("Continuous" trials) continued until the 6MWT had concluded.

Footfall data were processed following standardized GAITRite workflows, and temporal-spatial measures (cadence, stride length, step length, etc.) were derived. TSP results were analyzed to compare participants' performance during the Discrete trials to those from the Continuous trials. Paired t-tests (α=0.05) were used to assess significant differences between walking conditions. Subsequent 2-way ANOVA analyses (*gmfcs, condition*) were performed to understand the impact of functional rating (GMFCS level) on these differences.

RESULTS

Key temporal-spatial measures collected during Discrete and Continuous trials are presented in Table 1, along with paired t-test results. ANOVA analysis identified GMFCS level as a differentiating factor in measures of velocity, cadence, and step time. No significant interaction effects were observed.

Table 1: Comparison of TSPs presented as **mean (SE)**. Significant differences between conditions ($p<0.05$) are indicated by †.

Measure	Discrete	Continuous	p
Velocity [cm/sec]	108.27 (5.32)	122.63 (4.55)	0.0085 †
Cadence [steps/min]	108.96 (2.54)	117.31 (2.7)	0.0052 †
Step Time [sec]	0.56 (0.02)	0.52 (0.01)	0.0027 †
Step Length [cm]	60.51 (2.31)	63.55 (2.05)	0.0321 †
Cycle Time [sec]	1.11 (0.03)	1.03 (0.02)	0.0041 †
Stride Length [cm]	119.34 (4.61)	125.71 (3.65)	0.0272 †
Stance Duration [% Stride]	63.21 (0.95)	63.15 (1.09)	0.8416
Swing Duration [% Stride]	36.79 (0.95)	36.87 (1.09)	0.8693

DISCUSSION

The significant differences observed between the Discrete and Continuous testing scenarios indicate faster walking speeds, attributable to both higher cadence and longer stride length. Reductions in step and cycle times are similarly associated with these changes, but notably, the overall portions of the stride spent in stance and swing remain unchanged. Differences associated with GMFCS level were observed between the groups, with GMFCS II participants demonstrating slightly reduced function compared to GMFCS I participants. However, the absence of an interaction effect indicated that GMFCS levels did not significantly affect the nature of differences between the Discrete and Continuous conditions.

DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

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Reachable Workspace After Mastectomy: A Case Series

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PATIENT HISTORY

This study assessed the impact of mastectomy/breast reconstruction on upper extremity reachable workspace in 3 women. Participant 1 (63 y/o) underwent bilateral mastectomy with pre-pectoral tissue expander placement and left sentinel lymph biopsy for a diagnosis of left side, stage 1, grade 2 invasive ductal carcinoma. Participant 2 (36 y/o) underwent bilateral mastectomy with concomitant pre-pectoral tissue expander placement and right sentinel lymph node biopsy for right side, stage 0, grade 3 ductal carcinoma in situ followed by implant reconstruction. Participant 3 (19 y/o) underwent right partial mastectomy with immediate subpectoral implant reconstruction for a benign restrictive breast hemangioma.

CLINICAL DATA

All of the participants had standard postoperative activity restrictions. Participant 1 had reduced preoperative left shoulder mobility due to a left-side humeral head fracture prior to mastectomy. Participant 2 developed seromas at all three surgical sites, which required aspirations. Participant 3 had no known complications.

MOTION DATA

Reachable workspace was measured using a three-dimensional motion capture system (Qualisys, Gothenburg, Sweden). Retroreflective markers were placed on anatomical bony landmarks on the spine, sternum, humerus, wrist, and hand. Data collection was carried out separately on each arm using real-time feedback, as previously described [1]. Normative data of the dominant arm of 19 young adults (avg. 20.6yrs, 14 M, 5F) was used to compare results. Differences of ten percent or greater in percent workspace reached were considered clinically relevant changes.

OUTCOME

Participant 1 had reachable workspace data collected six days prior to bilateral mastectomies as well as three months and eight months after the procedure. At pre-operative baseline, the patient demonstrated reduced outer reachable workspace on the left arm compared to the right arm in four out of the six octant regions which is consistent with prior humeral head fracture prior to mastectomy. Three months post-op (**Fig. 1**), a decrease in workspace was shown particularly in by the right arm in the superior and inferior posterior ipsilateral regions, as well as in the right superior and inferior anterior contralateral regions. By 8 months post-op, the deficits observed in the 3-month post-op analysis were all partially improved in regions that were reduced with the superior/posterior/ipsilateral octant being the least improved.

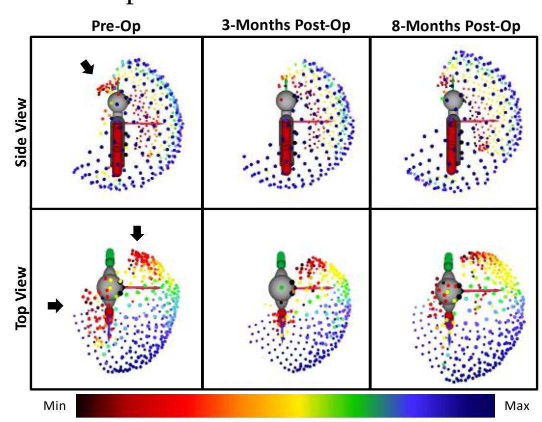

Figure 1: Participant 1 outer reachable workspace of right arm. Black arrows highlight regions of postoperative deficits.

For participant 2, reachable workspace was assessed monthly beginning 7 weeks after mastectomy until 4 months after surgery. Reachable workspace was again assessed 7 weeks after implant reconstruction until 6 months after surgery. Patient 2 demonstrated decreased outer percentage workspace reached after both mastectomy and reconstruction, particularly in superior/anterior/ipsilateral and superior/posterior/ipsilateral regions. Workspace returned to baseline values about 4 months post-mastectomy and 4-6 months after implant reconstruction. Similarly, the inner workspace percentage followed the same pattern of recovery, returning to baseline or greater 4 months after mastectomy and 4-6 months after implant reconstruction.

Participant 3 had reachable workspace data collected on both arms 11 years after right partial mastectomy and immediate implant reconstruction. In the outer workspace (**Fig. 2**), the unaffected left arm demonstrated reduced superior/posterior/ipsilateral workspace. The affected right arm demonstrated reduced inferior/anterior/contralateral workspace. For inner regions, the affected right arm exhibited reduced ipsilateral workspace compared to the left and normative data.

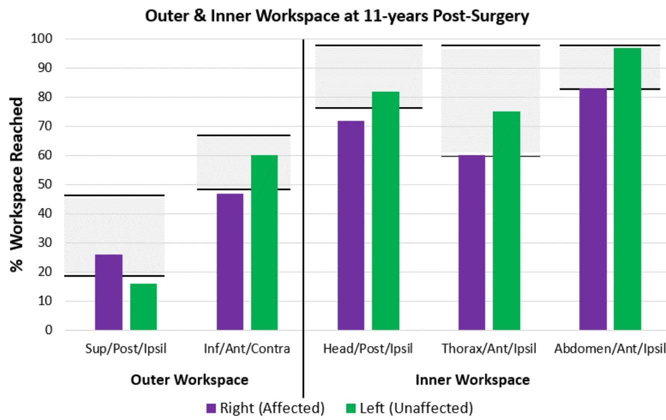

Figure 2: Outer (L) and inner (R) workspace results for participant 3. Gray bands +/- one SD about the mean of the normative dataset.

SUMMARY

This study demonstrates a proof of concept for the use of reachable workspace as an assessment tool in patients undergoing mastectomy and breast reconstruction surgeries. Although the shoulder is not directly addressed in these procedures, they have previously been associated with decreased shoulder range of motion, persistent shoulder pain, and reduced patient reported outcomes; however, range of motion measures have largely been limited to planar measures [2,3]. In this study, behind-the-body and overhead outer reach as well as the behind the head and thoracic/abdominal ipsilateral inner regions were most affected. Reach in these superior/posterior regions and behind the head requires stretching across pectoralis major and anterior chest wall due to abduction/cross-body abduction of the shoulder. Reach in the anterior, ipsilateral thoracic/abdominal regions requires shoulder extension causing stretch of the pectoralis major. Stretch across the anterior chest wall and operative site could lead to these limitations. These findings suggest that reachable workspace is a useful tool for functional evaluation and outcomes assessment after breast surgery. Expansion of this technique to a larger cohort may characterize time to recovery of reachable workspace and potential differences based on selected surgical technique.

DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

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SEATED VS. STANDING SPINE KINEMATICS: THE IMPORTANCE OF ESTABLISHING NORMATIVE DATA FOR NON-AMBULATORY POPULATIONS

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INTRODUCTION

Three-dimensional motion analysis of spine kinematics has largely been focused on functional movements such as walking, balance, and sports activities. The evaluation of spinal motion in ambulatory children with adolescent idiopathic or neuromuscular scoliosis before and after posterior spinal fusion (PSF) has advanced our understanding of fusion-level implications. However, there remains a significant knowledge gap regarding PSF in non-ambulatory children or those lacking functional ambulation skills, as their spinal kinematics have been largely unexplored. Investigating active spinal kinematics in non-ambulatory children who can sit independently may provide valuable insights for orthopedic surgeons and care teams in planning and assessing pre- and post-operative functional abilities. Comparative data on seated spinal kinematics can highlight post-operative movement restrictions and their impact on activities of daily living (ADLs), such as eating, toileting, and playing.

CLINICAL SIGNIFICANCE

Understanding the differences in spinal motion between seated and standing positions provides critical baseline data, aiding in the identification of post-surgical movement restrictions and their implications for essential ADLs. Establishing normative control data for seated spinal movement is essential to effectively interpret post-operative kinematic changes in non-ambulatory children.

METHODS

A comparative study was conducted using 22 control subjects with no known musculoskeletal diagnoses. Each subject performed the standardized Wilks spine protocol in standing and a modified Wilks seated spine protocol. Movements assessed included forward flexion (bend and tuck), extension, lateral bending (right and left), and rotation (right and left). Spinal segments were defined as follows: total spine is thoracic segment relative to (r.t.) pelvis, thoracic spine is r.t. the lumbar segment, lumbar spine is r.t. the pelvis segment, and the pelvis is r.t. the lab. Kinematic differences between seated and standing positions were analyzed using the Wilcoxon signed-rank test to assess differences in spinal motion across the sagittal, frontal, and transverse planes.

RESULTS

Flexion movements revealed significant differences between standing and seated positions in the primary sagittal plane. Seated thoracic flexion increased by 18.3° and 12.7° for the bend and tuck tasks, respectively, while lumbar flexion and pelvic motion were significantly reduced by 17.0° and 15.8° in the lumbar spine, and 21.5° and 19.5° in the pelvic for bend and tuck respectively. For extension, sagittal pelvic movement was significantly reduced by 15.3° in the seated position. Lateral bending movement displayed significant differences across planes. Thoracic movement in the transverse plane decreased significantly by 5.7°. Lumbar and pelvic movement was also significantly reduced in frontal and transverse planes. The rotation movements showed differences in all planes. In the sagittal plane, forward flexion increased by 6.9° in the seated position for the lumbar spine and decreased by 4.5° in the pelvic region. In the frontal plane, total spine and pelvic motion were reduced in the seated position by 16.5° and 1.9°, respectively, while lumbar movement increased by 2.0°. In the transverse plane, rotation differences were significant across all spinal regions.

DISCUSSION

Seated spinal kinematics exhibit unique motion patterns compared to standing positions, particularly in flexion in the sagittal plane and lateral bend and rotation in the frontal and transverse planes. The results indicate that seated positions significantly limits pelvic motion across all planes, with the effect diminishing progressively up the spine. Lateral bending and rotation differences were pronounced in seated positions, underscoring the need for positional context in understanding out-of-plane movement. The nature of the seated position will cause limitations in total movement, highlighting the importance of developing normative seated control data to accurately interpret post-surgical changes in non-ambulatory populations. The greatest clinical utility of the seated spine motion data will lie in determining how treatment affects ADLs for this population, rather than comparing motion changes to a standing spine population. Future research should focus on the functional implications of these differences for activities of daily living and surgical planning.

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DISCLOSURE STATEMENT

Kirsten Tulchin-Frances is a board member of GCMAS.

Table 1: Movement Differences, Standing vs Seated Protocol

	Forward Flex Bend	Forward Flex Tuck	Extension	Lateral Bend	Rotation
Sagittal Plane					
Total Spine	0.291	0.833	0.586	**0.003 (+4.3)**	0.062
Thoracic Spine	**<0.001 (+18.3)**	**<0.001 (+12.7)**	0.070	0.053	0.152
Lumbar Spine	**<0.001 (-17.0)**	**<0.001 (-15.8)**	0.469	0.484	**0.009 (+6.9)**
Pelvis	**<0.001 (-21.5)**	**<0.001 (-19.5)**	**0.007 (-15.3)**	0.179	**0.004 (-4.5)**
Frontal Plane					
Total Spine	0.381	0.846	0.118	0.077	**<0.001 (-16.5)**
Thoracic Spine	0.931	0.229	0.277	0.081	0.051
Lumbar Spine	0.080	0.639	0.518	**0.002 (-0.6)**	**0.001 (+2.0)**
Pelvis	0.745	0.299	0.177	**0.002 (-3.9)**	**0.004 (-1.9)**
Transverse Plane					
Total Spine	0.871	0.845	0.836	**0.001 (-3.7)**	**<0.001 (-8.9)**
Thoracic Spine	0.487	0.626	0.518	**0.010 (-5.7)**	**0.026 (+5.0)**
Lumbar Spine	0.194	0.649	0.897	**<0.001 (-4.7)**	**0.037 (-2.5)**
Pelvis	0.626	0.408	0.185	**0.003 (-1.8)**	**<0.001 (-31.4)**

*p values (motion gained or lost in seated position)
Shaded: in plane motion

VALIDITY OF MARKERLESS MOTION CAPTURE DETECTING SPINE RANGE OF MOTION IN SCOLIOSIS

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INTRODUCTION: The "gold standard" for clinical motion analysis is marker-based systems, where reflective markers placed on anatomical landmarks track joint and segment movement via infrared cameras. However, these systems are costly, challenging to use outside labs, and intolerable to many patients with neurodevelopmental disorders. Markerless motion capture offers a flexible alternative to these issues but requires additional validation before clinical use, especially for pediatrics. For instance, markerless systems reduce the need for marker application and post-processing time. Smaller scale validation studies comparing systems primarily focus on walking; yet, in Shriners Motion Analysis Centers, other movements such as spine range of motion are also critical to informing care. The purpose of this study was to evaluate the validity of a markerless motion capture system when compared to a marker-based system during spine range of motion in scoliosis patients.

CLINICAL SIGNIFICANCE: This study tests the validity of spine range of motion between marker-based and markerless motion capture.

METHODS: Reflective markers were placed on the patient during a clinical spine evaluation according to the Texas Scottish Rite multi-segment spine model [1] by certified physical therapists. After marker placement, each visit consisted of a static standing trial and dynamic motions including flexion, extension, lateral side bending and rotation. All patients completed three cycles for each motion. A marker-based motion capture system comprised of 12 optical, infrared cameras (Vantage V16, Vicon Motion Systems Ltd, Oxford, UK) tracked reflective markers (60 Hz). Eight FLIR cameras (Blackfly S BFS-U3-23S3C, Teledyne Vision Solutions, Waterloo, ON, Canada) concurrently captured digital video (1920x1200p; 60 Hz) for a markerless system (Theia3D, Theia Markerless, Kingston, ON, Canada). The spine model calculated marker-based joint angles in Vicon BodyBuilder for the following segments: Thoracic, Lumbar, Total Spine, and Pelvis. Theia3D computed the transformation matrices for the markerless data which were used to calculate joint angles for the trunk, pelvis, hips, knees, and ankles. For the case of this study, the total spine motion of the marker-based model was compared to the trunk angles of the Theia3D output. A total of three peak values of interest per patient were analyzed for each dynamic trial. Comparisons between the marker-based and markerless outputs were made using Root Mean Square Error (RMSE) for each kinematic variable [2] and Bland-Altman Plots.

RESULTS: In this study, we evaluated 37 patients (31 females; 16.2 ± 2.8 yrs) with Adolescent Idiopathic Scoliosis (AIS) with a clinical evaluation for scoliosis patients at our institution. The markerless system reliably tracked motion but showed consistent offsets (Fig. 1A), with R^2

values between 0.33-0.77. Most RMSEs were below 10°, except for spinal extension (RMSE = 17.7°) (Fig. 1B). Biases were significant in all movements except right rotation, indicating movement-specific, systematic over- or underestimation by the markerless system. Agreement limits between systems averaged 30° across movements.

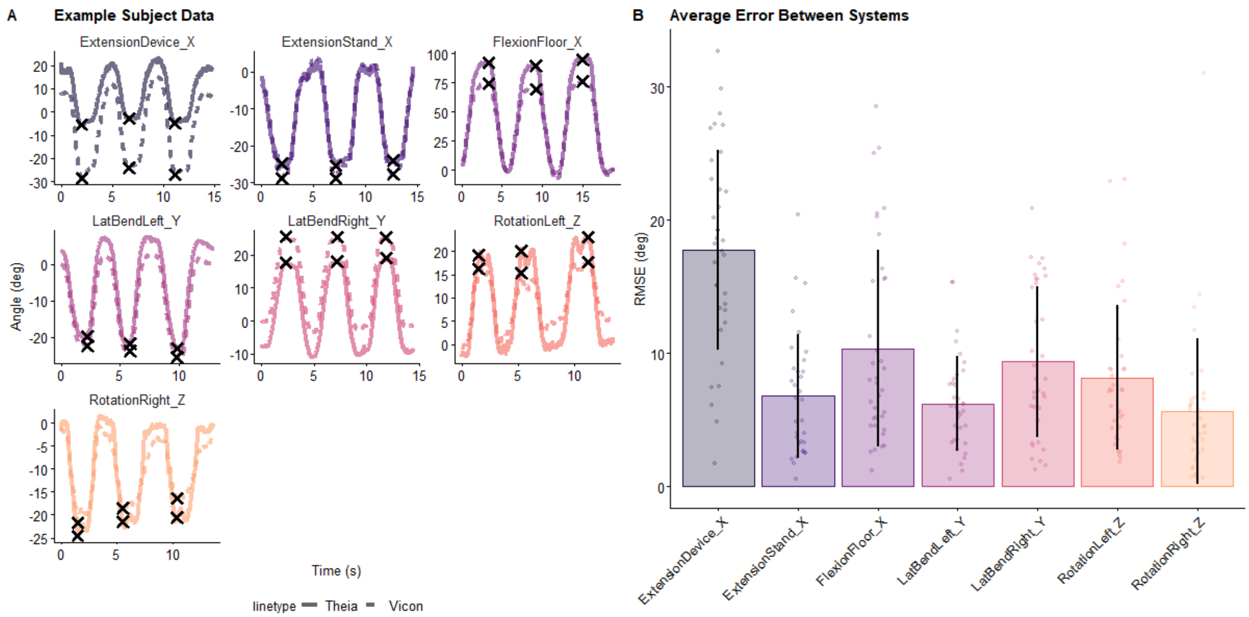

Figure 1. **A)** Kinematic traces for one example subject for all seven movements. Peak values of interest are indicated with an "X." Dashed lines are marker-based, solid are markerless. **B)** Mean (± SD) root mean squared error (RMSE) of the detected peak values between marker-based and markerless systems. Points indicate individual subject RMSE.

DISCUSSION: Altogether, this work highlights that caution should be taken when considering markerless systems for clinical spinal use; however, it does hold promise dependent upon additional validation and establishment of a normative dataset. For example, the largest differences were during spine extension on a Roman Chair extension device, which may be expected as it obscures the anterior pelvis from view. Consistent offsets in all motions were also observed, which may be due to underlying assumptions regarding pelvis orientation; however, these offsets were addressed by Theia3D in a recent update to their model. Future work will use this updated model, and should additionally compare the pelvis segments between models, and should control for additional variables specific to the scoliosis population, such as curve severity.

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Age-Related Changes in Spinal Range of Motion: A Motion Capture Analysis

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INTRODUCTION
Spinal flexibility is essential for mobility and physical function. Restrictions in range of motion (ROM) and limited flexibility of the lumbar spine, particularly in the coronal and sagittal planes, can significantly increase the risk of developing lower back pain and susceptibility to injury [1]. Although spinal ROM changes across the lifespan have been well documented, much of the existing research relies on traditional measurement methods that may not capture the dynamic nature of movement. As a result, the impact of spinal ROM changes with age, particularly in the pediatric and young adult populations, have not been fully explored through the real-time analysis that motion capture technology can provide. Comparing clinical populations to age-matched controls is essential for identifying the specific effects of aging on spinal ROM, as this comparison helps clarify how age-related changes contribute to movement limitations and injury risk. Such comparisons can ultimately lead to more effective injury prevention, treatment, and rehabilitation strategies.

CLINICAL SIGNIFICANCE
A thorough evaluation of spinal ROM via 3-D motion analysis can provide valuable insights into the biomechanical impact of aging on spinal flexibility and help guide strategies to mitigate the effects of aging on the spine.

METHODS
53 typically developing controls (age 5.1-35.1yr, 58% male) completed 3-D motion analysis testing to evaluate spinal flexibility and range of ROM. Participants completed a standardized protocol including forward bend, forward tuck, standing extension, lateral bending, and rotation. Data were processed using the Wilk multi-segment spine model (MTSM) which compares *thoracic* movement relative to (r.t.) the lumbar segment, *lumbar* movement r.t. the pelvis, the *pelvis* r.t. the global coordinate system and *total spine* motion as the thoracic movement r.t. the pelvis segment. Data were analyzed using a Pearson correlation coefficient.

RESULTS
During flexion movements, the strongest correlations were observed in the sagittal plane. Specifically, age-related decreases in ROM were highly correlated in the total spine movement during both forward bend (r=-0.66) and forward tuck (r=-0.70). Segmental and planar correlations are summarized in Table 1. In contrast, correlations in standing extension were relatively low, with the total spine showing a minimal correlation (r=-0.29). Moderate correlations were noted during lateral bending, primarily in the frontal and transverse planes. Thoracic ROM showed moderate correlations in both the coronal (r=-0.35) and transverse (r=-0.32) planes during lateral bending. During rotation movements, moderate positive correlations in total spine rotation were observed with age (r=0.41), largely attributed to changes in thoracic

ROM (r=0.34) rather than lumbar motion (r=-0.21). Overall, there were minimal differences in spinal ROM during lateral bending and rotation, although some changes in out-of-plane motion in the spine and pelvis were noted, as detailed in Table 1.

Table 1: Correlations between segmental spine range of motion and age

	Total Spine	Thoracic	Lumbar	Pelvis
	Forward Bend			
Sagittal	-0.66*	-0.48	-0.48	0.53
Coronal	-0.05	0.20	0.05	-0.03
Transverse	0.19	0.22	-0.21	-0.03
	Forward Tuck			
Sagittal	-0.70*	-0.51	-0.50	0.63*
Coronal	-0.13	-0.07	0.01	-0.09
Transverse	0.09	0.21	-0.06	0.32
	Standing Extension			
Sagittal	-0.37	-0.25	-0.09	0.07
Coronal	-0.29	-0.07	-0.42	0.13
Transverse	0.43	0.32	-0.10	-0.14
	Lateral Bend			
Sagittal	-0.26	-0.18	-0.09	-0.04
Coronal	-0.22	-0.35	0.21	0.04
Transverse	-0.08	-0.32	0.45	-0.26
	Rotation			
Sagittal	-0.10	-0.16	0.19	0.07
Coronal	-0.35	-0.05	-0.28	0.45
Transverse	0.41	0.34	-0.21	-0.21

***Note:** *indicates significant correlation*

DISCUSSION

The findings of this study reveal that age-related changes in spinal ROM vary across different movements. During forward bending, a decrease in total spine movement with increasing age was observed, with older individuals relying more on pelvic tilt to compensate for reduced spinal mobility. This pattern aligns with existing research that demonstrates reduced spinal flexibility with age, particularly in the sagittal plane, which may contribute to altered movement strategies in adults [2]. The reliance on pelvic motion to compensate for decreased spinal flexibility suggests that individuals may adapt by shifting some of the movement to the pelvis to maintain functional mobility.

In contrast, the analysis of standing extension revealed that this movement typically has a more limited range of motion across all groups, and therefore did not show a strong correlation with age. Spinal ROM during lateral bending and rotation showed minimal differences across age groups, suggesting that age-related changes in these movements may not be as pronounced as in forward bending.

These findings indicate that while spinal ROM generally decreases with age, compensatory strategies such as increased pelvic tilt and changes in out of plane motion patterns may help maintain overall mobility. Further research could explore these compensations, the relationship between flexibility and overall activity level, and the potential implications for injury prevention and functional performance across the lifespan, as well as providing age-matched spinal range of motion to better assess pediatric clinical populations.

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DISCLOSURE STATEMENT

Kirsten Tulchin-Francis is a board member of GCMAS.

Biomechanical Analysis of Trunk and Spinal Kinematics in Idiopathic Scoliosis: A Review of Current Efforts in Three-Dimensional Motion Capture

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INTRODUCTION

Scoliosis is a complex three-dimensional deformity of the spine, characterized by coronal curvature which most commonly arises during periods of rapid skeletal growth. Adolescent idiopathic scoliosis (AIS) presents as a diagnosis of exclusion once neuromuscular disorders, skeletal malformation, or syndromic disorders have been ruled out. The condition affects 2–3% of the adolescent population (10-16 years), with the preponderance of reported cases being in females, who face a higher risk of progression.[1-2] The influence of the coordinated movement patterns of the trunk to mechanical efficiency has been emphasized in the extant literature; however, such patterns may be altered in those with AIS due to restrictions in dynamic mobility and a shifted center of mass[3]. Despite this, most research on the effect of AIS on movement has been indirect, focusing on lower extremity and pelvis kinematics, with a critical gap in directly studying trunk kinematics.

CLINICAL SIGNIFICANCE

A review of the literature on trunk kinematics, obtained through marker-based 3D motion capture in individuals with AIS, is essential for understanding the dynamic properties of the spine, and helping to develop standardized models and protocols to advance knowledge in this population.

METHODS

The PUBMED database was searched by two independent reviewers using a set of standardized keywords: "Motion capture", "Motion analysis", "Spine", "Trunk", "Idiopathic scoliosis", "AIS", "Adolescent idiopathic scoliosis", "Gait", "Kinematics", and "Biomechanics". Reviewers followed a multi-step appraisal process, starting with relevancy assessment based on article titles and elimination of duplicate results. The second stage of study selection included a full-text analysis for inclusion criteria: patients with AIS and no other known medical confounders to ambulation or mobility status; pre-intervention data; and reported trunk/spine kinematic data obtained by marker-based three-dimensional motion capture. Studies were otherwise excluded if: their principal aim was to validate mathematical modeling or finite element analysis; if kinematic data were derived from simulations; were not a full-text article. The final stage of study selection involved critical analysis using the Modified Non-Randomized Trial Quality Index from the Joanna Briggs Institute (JBI).[4] Disagreements were resolved through discussion until consensus was reached; if necessary, a third reviewer with over 10 years of experience in motion capture and orthopedics provided the final determination.

RESULTS

The search produced 3,564 results. Assessment of article titles eliminated 3,342 irrelevant studies. A further 72 studies did not satisfy inclusion criteria upon full-text analysis. Five studies were eliminated during critical appraisal. A total of 22 studies, ranging in publication date from 1998-2022 fit the inclusion criteria and were appraised to a high methodological quality. Review of study characteristics is presented in Table 1.

Table 1. Study Characteristics

Model	Tasks	Segments	Trunk Variables	Control	Intervention
Custom (n=14)	Gait (n=14)	Single (n=12)	Posture/Alignment (n=8)	Y (n=12)	PSF (n=10)
PiG (n=8)	Uniplanar Motion (n=6)	Multi (n=10)	ROM (n=15)	N (n=10)	VBT (n=2)
	Balance (n=2)		Intersegmental Interaction (n=5)		None (n=10)
	ADL (n=2)				

DISCUSSION

The present study underscores the heterogeneity in the literature on trunk dynamics in patients with adolescent idiopathic scoliosis (AIS). Fifteen unique models were identified. Concerns arise with consideration that over half of models utilized only consider the trunk to be a single segment, overlooking the potential regional and intersegmental kinematic differences especially prevalent in the asymmetrical anatomy of patients with AIS. In addition to a potentially oversimplified model of the trunk, the majority of data were captured during low impact, low velocity tasks under circumstances where kinematic requirements are low and may not reach ranges that would reveal significant dynamic limitations. Many adolescents with AIS, particularly athletes, engage in higher intensity activities than are represented in the literature. If the dynamic characteristics of the spine in such tasks is not well understood, these patients may be at a greater risk for orthopedic sequelae or poor functional outcomes post-intervention. By restricting the range of movements captured and failing to consider the trunk's intricate segmentation, current methodologies are limited in their ability to provide a comprehensive understanding of dynamic AIS-related trunk dysfunction.

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DISCLOSURE STATEMENT

Kirsten Tulchin-Frances is a board member of GCMAS

Assessing the Potential for Abnormal Gait Patterns in Athletes with Spondylolysis

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INTRODUCTION

Spondylolysis, a stress fracture of the pars interarticularis, is a common overuse injury in youth athletes engaged in sports involving repetitive hyperextension and rotational movements. This condition often manifests as low back pain (LBP) and can be exacerbated by increased physical activity [1]. While most athletes can return to their sport following rehabilitation and physical therapy, the biomechanical implications of spondylolysis on gait remain an area of concern. Given that efficient gait mechanics are critical for athletic performance, understanding potential compensatory movement patterns associated with this condition is essential for optimizing rehabilitation strategies and injury prevention.

Despite extensive research on the diagnosis and treatment of spondylolysis, limited studies have explored its impact on gait biomechanics. The presence of a lumbar defect may lead to altered lumbopelvic coordination, compensatory muscle activation, or asymmetrical load distribution. It has been reported that during walking, coordination of motion between the thorax and the lumbar spine/pelvis was significantly more in-phase in the persistent LBP groups [2]. However, there is a lack of comprehensive studies assessing whether these biomechanical adaptations significantly affect athletic performance or predispose individuals to secondary musculoskeletal injuries. This study aims to bridge this gap by analyzing the gait mechanics of athletes with spondylolysis.

CLINICAL SIGNIFICANCE

An understanding of how spondylolysis impacts gait mechanics will provide information regarding the potential compensatory movement patterns. This information may influence the development of targeted rehabilitation protocols that not only facilitate a safe return to sport but also mitigate long-term biomechanical deficits associated with spondylolysis.

METHODS

This study examined gait in10 athletes diagnosed with spondylolysis (SP Group, age 15.9 ± 1.8 years, 60% male). At the time of gait analysis, participants were an average of 13.6 months post-injury. 3D motion analysis data was processed using the Shriners Children's Gait Model (SCGM) [3], and a representative trial for each side was analyzed. Non-parametric Man-Whitney U tests were used to compare gait data of patients with spondylolysis with typically developing (TD) controls.

RESULTS

Regarding injury classification, 65% were diagnosed with acute spondylolysis, while 5% had chronic cases. Most injuries were located at the L5 vertebra (50%), followed by L4 (30%), with 20% of cases involving both levels. Two individuals required surgical intervention, including one patient with a concurrent diagnosis of adolescent idiopathic scoliosis (AIS) who later developed spondylolisthesis. On the day of the gait analysis, 2/10 participants reported experiencing LBP.

Gait deviations in the SP group were primarily noted in the sagittal plane. Trunk position remained more anterior for the SP group throughout all phases of the gait cycle (p=0.007); however, the overall average difference was only 2.5° compared to (TD) controls. Sagittal and frontal plane range of motion (ROM) of the trunk was no different between groups (p=0.185, p=0.232). Decreased overall trunk rotation ROM was noted in the SP group (p=0.006), with decreased peak rotation occurring notably during swing (p=0.015).

The SP group showed similar average pelvic position and ROM to TD controls throughout the gait cycle (p=0.981, p=0.326). Hip flexion ROM was reduced during both stance (-3.7°, p=0.002) and swing (-4.8°, p=0.005), with the SP group having a reduced peak hip flexion during swing compared to controls (-2.8°, p=0.011). Hip motion in the frontal plane was also altered, with overall decreased ab/adduction hip ROM throughout the gait cycle in the SP group (p=0.037). The SP group also demonstrated a maximum hip abduction position during stance occurring 8% earlier than TD controls (p=0.046) and increased adduction during swing (p=0.044). Additionally, the SP group had altered knee flexion kinematics, with decreased peak knee flexion during swing (-2.5°, p=0.016). They also demonstrated a delayed peak knee extension at terminal swing by 3.5% of the gait cycle (p=0.014).

DISCUSSION

This study highlights the biomechanical deviations seen in athletes with spondylolysis, particularly during gait. Athletes with spondylolysis exhibited altered trunk position throughout the gait cycle, possibly a compensatory strategy to reduce strain on the lumbar spine. Additionally, there was a noticeable decrease in trunk rotation, particularly during swing, which suggests limited spinal mobility to avoid exacerbating the injury and/or pain. The altered hip and knee kinematics may contribute to a less efficient gait and potentially increase the risk of secondary musculoskeletal injuries.

These findings underscore the importance of understanding how spondylolysis impacts gait in youth athletes. Compensatory movement patterns, while protective in short term, may lead to long-term biomechanical deficits and secondary injuries. Targeted rehabilitation protocols aimed at restoring normal trunk, hip, and knee mechanics are essential for optimizing both performance and injury prevention in athletes with this condition.

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DISCLOSURE STATEMENT

Kirsten Tulchin-Francis is the 2025 GCMAS Conference co-chair.

The Association Between Strength Changes and Kinematic Changes in High School Cross Country Runners Following a Competition Season

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INTRODUCTION

Cross country running remains a popular activity among high school athletes, with nearly 450,000 participants during the 2023-24 school year. [1] Annually, almost one in three adolescent runners reports a running related injury (RRI) [2] with female runners reporting first-time and recurring injuries at a significantly higher rate than males. [3]

While these injuries are associated with a host of negative sequelae, adolescent and teen runners are not well-represented in the scientific literature. Findings from adult studies are often leveraged for these groups clinically, despite growth and maturational factors that differentiate them from adults. Prior work by our group [4] has identified maturation influences on pelvic and hip kinematics, with larger effects seen in female runners during later stages of puberty. The purpose of this study was to investigate kinematic changes in these runners over the same timeframe. We hypothesized that reductions in knee strength would be associated with changes in key joint kinematics, particularly at the knee.

CLINICAL SIGNIFICANCE

Risk factors for RRIs are understudied in adolescent and teen runners. Understanding changes in strength and kinematics over the course of a competitive season may help clarify the need for intervention or heightened injury surveillance at key time points in a season.

METHODS

Forty (40) adolescent and teen runners were recruited for participation in a larger study involving daily activity surveillance and periodic lab assessments. Runners were between ages 13-19, with plans to compete in both cross country and track during the upcoming school year. This analysis uses a subset of 31 runners who completed >80% of the competitive season.

Strength and joint motion (kinematics) were measured during visits to the Motion Analysis Lab before (CC_{pre}) and after (CC_{post}) the cross country competition season. During each lab session, runners underwent 3D instrumented motion analysis (MAC Raptor System; Motion Analysis Corp., Rohnert Park, CA) while running on a Biodex RTM600 treadmill (Biodex Medical Systems; Shirley, NY) at a self-selected speed. Multiple (30+) strides were collected during the running activity, and average patterns were calculated and reported for the right side. Following motion analysis, runners underwent isokinetic concentric knee strength testing on a Biodex System 4 (Biodex Medical Systems; Shirley, NY) at 60 deg/sec. Average and peak torques were calculated from five trials. A paired t-test (α=0.05) identified significantly decreased knee extensor strength between visits, as well as significantly faster running speeds at the CC_{post} visit. Key kinematic measures were identified, and ANCOVA analysis was performed to clarify the nature of kinematic changes between visits (primary factors *sex* and *visit*, covariate *speed*).

RESULTS

Key findings are presented in Table 1. ANCOVA analysis found significant effects of sex on transverse plane ROM of the pelvis ($p=0.0002$), and a significant interaction between *sex* and *visit* was identified for coronal plane ROM of the pelvis ($p=0.0250$).

Table 1: Summary of key kinematic measures, stratified by *sex* and presented as **mean (SE)**. Significant pre/post differences are indicated by †.

	Male		*Female*	
Measure	**Pre**	**Post**	**Pre**	**Post**
Mean Knee Extensor Torque [ft-lbs]	91.1 (8.2)	79.8 (6.1)†	87.2 (5.3)	79.7 (4.8)†
Mean Knee Flexor Torque [ft-lbs]	45.8 (4.4)	43.6 (4)	43 (3.1)	42 (2.9)
Running Velocity [mi/hr]	7.4 (0.3)	8 (0.2)†	6.6 (0.2)	7.1 (0.2)†
Pelvis Coronal ROM [deg]	10 (0.5)	7.7 (0.4)†	9.5 (0.8)	9.9 (0.6)
Pelvis Sagittal ROM [deg]	10.6 (0.5)	10.5 (0.6)	11 (0.7)	11.5 (0.8)
Pelvis Transverse ROM [deg]	15.5 (1.2)	14.6 (0.9)	19.2 (1.2)	19.7 (1.4)
Peak Hip Extension [deg]	-10.3 (0.8)	-10.7 (1.3)	-9 (1.9)	-9.7 (1.2)
Peak Hip Flexion in Swing [deg]	43.7 (1.9)	43.7 (2.3)	43.7 (2)	46.7 (1.4)
Peak Knee Flexion in Load Response [deg]	40.2 (1.2)	40.3 (1.3)	40.1 (1.2)	42.1 (0.9)
Peak Knee Varus in Stance [deg]	-0.3 (0.9)	-0.4 (0.9)	1.5 (1.6)	-0.4 (0.4)
Peak Knee Valgus in Stance [deg]	-4.8 (1.1)	-4.2 (1.1)	-4.6 (0.6)	-4.8 (0.6)

DISCUSSION

Despite significant decreases in knee extension strength over the course of a cross country competition season, minimal changes were noted in running kinematics at CC_{post} after controlling for running speed. In contrast to our initial hypothesis, there were no significant relationships between knee extensor strength reductions and knee kinematics. The significant decrease in pelvis coronal plane ROM for males indicates a reduction in pelvic drop and better maintenance of pelvic position during single limb stance time. This suggests an increase in strength and/or control. Additional measures may be warranted to understand the relationships between strength, form, and movement patterns over the course of a competitive season.

ACKNOWLEDGMENTS

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DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

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Assessing Trunk Kinematics in Athletes With Pathology: A Multi-Segment Model Approach

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INTRODUCTION

Evaluating trunk motion in athletes, particularly those with underlying pathologies such as adolescent idiopathic scoliosis (AIS) or anterior cruciate ligament (ACL) injures, is crucial for understanding compensatory mechanisms, risk of injury, and rehabilitation strategies. Traditionally, single-segment trunk models are used during motion analysis, which may oversimplify trunk biomechanics and overlook critical motion in different regions of the spine. In athletes with AIS, asymmetry of the spine may cause uneven load distribution and altered motion patterns, predisposing them to injury or impacting their athletic performance. Similarly, athletes with ACL injuries may exhibit compensatory movements to mitigate knee instability. A more detailed analysis using a multi-segment trunk model (MSTM) can provide comprehensive insights into the distinct motions of the spinal segments during athletic activities.

CLINICAL SIGNIFICANCE

A MSTM evaluating thoracic and lumbar motion during lateral shuffle will provide information regarding compensatory spine motion in athletes with AIS or ACL injury compared to a single segment (SS) trunk model.

METHODS

20 typically developing individuals (age 20.5±6.9, 75% M), 6 athletes with AIS (age 15.8±1.1, 67% M), and 8 athletes six months post-ACL reconstruction (age 16.0±2.0, 50% M) completed 3-D motion analysis testing. Lateral shuffle data was processed using the Wilk, et al. multi-segment spine model (MSTM) and the PRiSM RIG single segment (SS) trunk model. The SS trunk is defined using markers on the thoracic segment (clavicles and C7) relative to (r.t.) the global coordinate system. The MSTM compares thoracic movement r.t. the lumbar segment, lumbar movement r.t. the pelvis, and pelvis r.t. the global coordinate system. Trunk range of motion (ROM) in the frontal plane was evaluated during the time the lead foot was planted on the forceplate before changing direction. Non-parametric Man-Whitney U tests and Spearman-rho correlations were used to analyze data.

RESULTS

There were no statistically significant differences in frontal plane trunk ROM based on age, sex, or handedness (r=0.15, p=0.74, 0.62). In the control group, total SS trunk frontal ROM during lateral shuffle was 12.7±6.2°. The individual segments showed 11.0±5.7° of thoracic ROM and 8.7±3.6° of lumbar ROM in the frontal plane. The correlation between the individual thoracic segment and the SS trunk frontal ROM was very low (r=0.031). In athletes with AIS, the thoracic and lumbar ROM was greater when shuffling in the direction opposite their major curve, although the sample size was too small for statistical analysis. The ACL group demonstrated similar SS trunk ROM (10.5±4.3°) to controls on their non-injured side, with thoracic and lumbar ROM being similar. However, on their injured limb, they showed increased trunk ROM (13.0±5.6°) compared to controls, with thoracic ROM being less than lumbar ROM.

DISCUSSION

The SS trunk is defined using markers in the thoracic segment, however this was not correlated with the thoracic spine segment in the MSTM, meaning motion in the lumbar spine is affecting overall motion of the trunk and is not being considered in a SS trunk model. This is critically important in the athletes with asymmetrical injuries and pathologies. In the patients with AIS, there were notable differences in the thoracic and lumbar spine ROM depending on the direction of their curve. In the ACL group, motion through the lumbar spine was greater than the thoracic spine on the injured side, which may represent compensatory spine movement to protect the injured limb. Use of a multi-segment spine should be considered when evaluating spine motion during sports tasks.

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DISCLOSURE STATEMENT

Kirsten Tulchin-Frances is a board member of GCMAS.

Hemophilia Severity Impacts Range of Motion During Simulated Sports Activities

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INTRODUCTION

Hemophilia is an X chromosome-linked bleeding disorder affecting 1 in 5000 males [1], in which deficiency in factor VIII or factor IX results in delayed clotting [2]. Of great concern for persons with hemophilia (PwH) is musculoskeletal bleeding that can cause severe arthropathy if not treated properly [1]. The Hemophilia Joint Health Score (HJHS) is a validated physical exam tool used to longitudinally track PwH's joint health, specifically of the ankle, knee, and elbow joints, where higher scores are worse [3]. However, the HJHS cannot identify dynamic joint mobility and function differences compared to persons without hemophilia, and further insight of when reduced function occurs is still needed.

CLINICAL SIGNIFICANCE

Identifying how dynamic joint mobility is associated with HJHS severity during simulated sports activities compared to healthy controls will allow for better prevention of joint damage and maintained quality of life in PwH.

METHODS

After informed consent and completion of an HJHS exam, 3D kinematic data were collected from 81 PwH and 32 age-matched healthy controls (**Table 1**) using Vicon motion capture with a modified plug-in gait model. Ten simulated sports activities were performed: barefoot walking (BFWalk), shoe walking (ShoeWalk), bilateral squatting (Squat), drop jump landing off a 31cm box (DJDropLand), vertical jump landing immediately after drop jump (DJJumpLand), 45° cut (Cut), bilateral deceleration after running (Decel), unilateral horizontal hopping (SLHorizontalHop), unilateral squatting (SLSquat), and unilateral vertical hopping (SLHop). After calculating joint angles using an X-Y-Z Cardan sequence, range of motion (ROM) for the ankle and knee joints during each activity was calculated and sorted into five groups, a control group and four hemophilia groups (Group 1 (G1), G2, G3, and G4) defined by quartiles of total joint HJHS from an existing HJHS database. Total joint HJHS identified the more affected side for analysis. Due to unequal sample sizes, a non-parametric Jonckheere-Terpstra Test ($p<0.05$) with a Kolmogorov-Smirnov post-hoc (corrected $p<0.005$) was used to compare groups (four hemophilia and one control) as an ANOVA/t-test alternative.

Table 1. Descriptive Characteristics of Study Participants

	Controls (n=32)	Hemophilia (n=81)			
	Controls	**Hemophilia Group 1**	**Hemophilia Group 2**	**Hemophilia Group 3**	**Hemophilia Group 4**
Quartile Range (HJHS)	---	≤ 10	10 > HJHS ≤ 15	15 > HJHS < 25	≥ 25
n	32	31	25	17	8
Age (yrs)	29.0 ± 16.0	15.5 ± 9.0	21.9 ± 13.1	32.0 ± 21.3	33.8 ± 7.8
Gender (M / F)	25 / 7	27 / 4	22 / 3	16 / 1	8 / 0
HJHS Mean ± STD	4.2 ± 3.4	6.5 ± 3.1	12.5 ± 1.1	18.1 ± 2.5	35.3 ± 7.0

RESULTS

PwH with a total HJHS ≥25 demonstrated reduced ROM for all activities in both ankle and knee joints compared to PwH having a total HJHS <25 and controls (**Fig. 1**). PwH with total HJHS <25 exhibited similar ROM compared to the controls. The ankle joint for PwH (total HJHS ≥25) showed more activities with reduced ROM compared to the controls than the knee joint. The activities showing significant differences for the more affected ankle were the BFWalk, Squat, DJDropLand, DJJumpLand, Cut, Decel, SLHorizontalHop, SLSquat, and SLHop, while the more affected knee only showed significant decreased ROM for Squat, SLSquat, and SLHop.

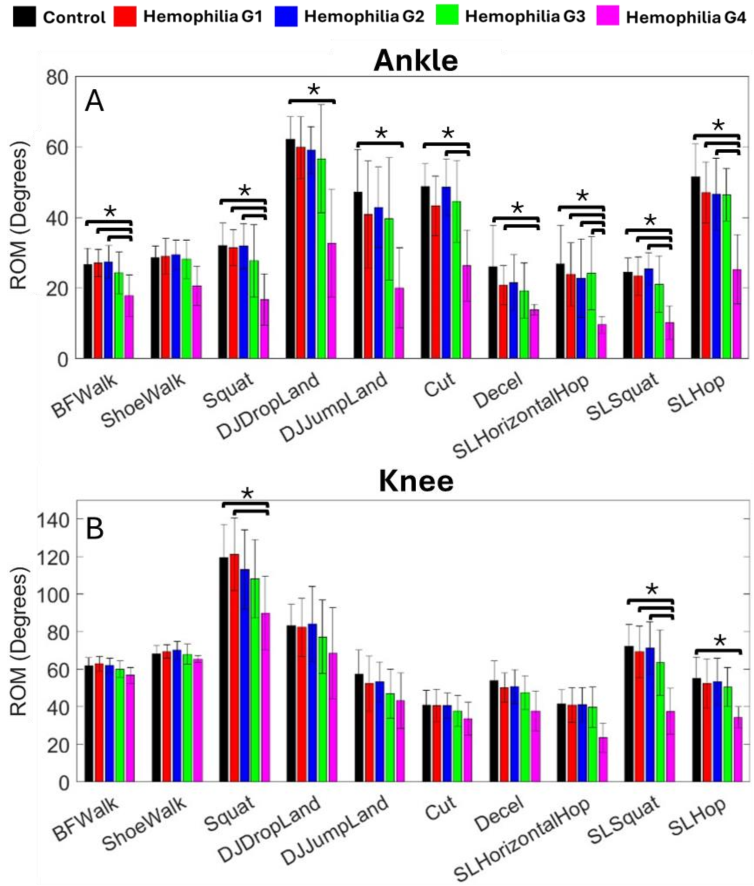

Figure 1. Peak ROM (degrees) during ten activities with standard deviation error bars for the more affected (A) ankle and (B) knee with *p<0.005.

DISCUSSION

Decreased ROM for PwH with a total HJHS ≥25 represents a threshold differentiating functional mobility loss in various activities of daily living. Preventative treatment is recommended to avoid PwH from reaching a total score ≥25 and the associated decreased dynamic joint mobility, function, and quality of life. Additionally, these results indicate that PwH with an HJHS <25 may have joint function more comparable to healthy controls, but further research is needed to evaluate other biomechanical factors and movement changes that may occur in PwH with less joint damage.

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DISCLOSURE STATEMENT

No conflicts of interest to disclose.

Return-To-Sport Motion Capture Testing After Posterior Spinal Fusion: Comparing Trunk Metrics Pre- Versus Post-Operation

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INTRODUCTION

Return-to-sport capabilities are an important factor for patients with adolescent idiopathic scoliosis (AIS) considering surgical correction, as physical activity participation has a known effect on quality of life. While most children who undergo posterior spinal fusion (PSF) or vertebral body tethering (VBT) return to sports post-operation (60% in 6 months, and more than 90% in 18 months [1]), current guidelines regarding when to return to sports are limited [2-3].

Computerized motion capture technology has been gaining traction as a tool to quantitatively assess return-to-sport readiness. Notably, three dimensional trunk position during dynamic sports tasks has been reported as a potential indicator for injury risk [4-5]. Given that trunk range of motion (ROM) is often reduced after surgery, understanding how this loss of ROM might affect patient injury risk when returning to sports is crucial.

However, to date no study has evaluated patients with AIS before and after PSF or VBT using motion capture return-to-sport testing. Therefore, in this work forward trunk flexion, lateral trunk lean, and pelvic obliquity during six dynamic tasks were compared pre- and post-PSF or VBT.

CLINICAL SIGNIFICANCE

Motion capture return-to-sport testing offers the opportunity to provide a quantitative assessment of return-to-sport readiness for patients with PSF or VBT, which may bolster clinical guidelines for this population.

METHODS

Patients with AIS 10-18 years old who actively participated in a sport and were scheduled to undergo PSF or VBT were recruited for the study at two institutions. Patients performed a return-to-sport test battery before surgery and six months after surgery, which included six dynamic tasks: heel touch, side step cut, lateral shuffle, deceleration, single hop, and drop jump. Each task was completed three times per side (except drop jump), and trunk and lower-limb kinematics/kinetics were collected via a motion capture system (Vicon Motion Systems Ltd, Oxford, UK) and in-ground force plates (AMTI, Watertown, MA, USA). Patients were scored based on the institution-established return-to-sport scale that considers hip stability, shock absorption, hip strategy, trunk stability, and pelvic stability categories. For this abstract, the trunk-centered components of the scoring algorithm were extracted and compared pre- and post-op: peak trunk flexion, peak lateral trunk lean, and peak pelvic elevation. Significant differences between pre- and post-operation participant means were indicated by a paired t-test.

RESULTS

Eleven patients (3 VBT, 8 PSF) completed pre- and post-operation return-to-sport tests. Due to the low population of patients with VBT, for this abstract we only analyzed the patients with PSF (8 female, mean age: 14.5 +/- 1.9 years, mean height: 165.89 +/- 7.26 cm, mean weight: 53.53 +/0 9.25 kg). Patients performed the left lateral shuffle with significantly reduced trunk flexion post-operation compared to pre-operation (average 7.69 +/- 6.84 deg reduction with p = 0.0155, Figure 1), which was reflective of the reduction in trunk flexion (though not significant) for all tasks except the heel touch. Lateral trunk lean and pelvic obliquity metrics were not significantly different pre- vs. post-operation for any task.

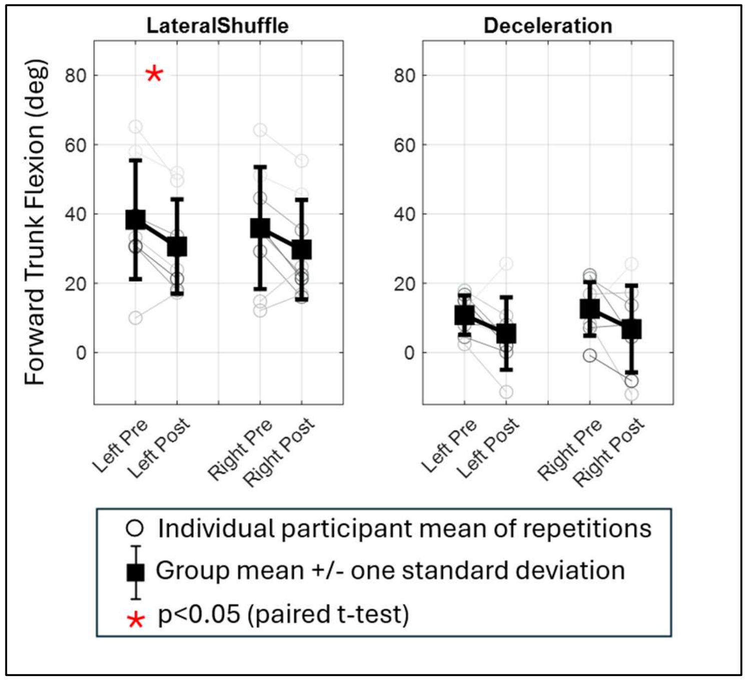

Figure 1. Forward trunk flexion for two example return-to-sport test tasks, pre- and post-operation. On average, participants exhibited reduced forward trunk flexion after PSF relative to before surgery, which was significant for the left lateral shuffle.

DISCUSSION

Patients exhibited reduced trunk flexion during most sports tasks compared to before surgery, with a significant reduction for the left lateral shuffle. Less forward trunk flexion results in a lower (i.e., worse) score in the return-to-sport test scoring algorithm, indicating a potential deficiency in return-to-sport readiness. Trunk lateral lean and pelvic obliquity did not yield significant differences pre- vs post-surgery. Future work will analyze more participants (goal of n = 40), including vertebral body tethering patients, which may provide more insights into return-to-sport readiness for each surgical approach and lowest instrumented vertebra.

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Lower Extremity Coordination Variability Reduces During an Incremental Cycling Test

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INTRODUCTION

Incremental cycling tests are a common method of accessing aerobic capacity for a variety of populations. The mainstay of these tests is the accumulation of fatigue among the participants, eventually reaching volitional failure for maximum effort protocols. While this fatigue accumulation is largely a result of peripheral factors (e.g. metabolite accumulation, failure to meet energy demands), central fatigue is also known to result in reduced force output in variety of scenarios. It has been hypothesized that the given multifactorial development on fatigue, new motor control strategies will emerge as the central and peripheral systems attempt to maintain the expected force and power output under conditions of fatigue [1]. Previous research has demonstrated that fatigue led to an altered neuromuscular response of the vastus medialis and vastus lateralis during time-to-exhaustion (TTE) trials in elite cyclists [2]; however, there is currently limited information available examining the effects of volitional fatigue on lower extremity limb coordination patterns. Therefore, the purpose of this study was to examine the influence of exercise-induced fatigue lower extremity limb coordination patterns during an incremental cycling test examining their VO2max.

CLINICAL SIGNIFICANCE

Understanding the influence that fatigue has on lower extremity coordination patterns may assist clinicians in planning or providing appropriate augmented feedback or guidance for patients, assisting with long-term improved motor patterns.

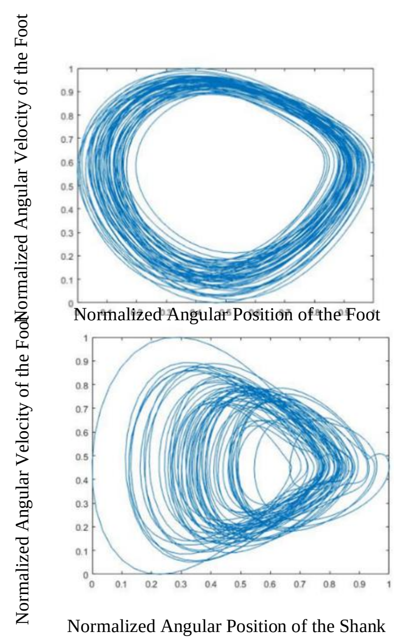


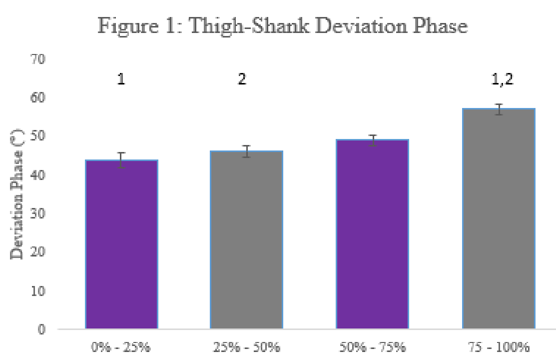
Figure 1: Sample Phase Plots for the Shank (top) and Foot (bottom) during a TTE Trial for a Single Participant.

METHODS

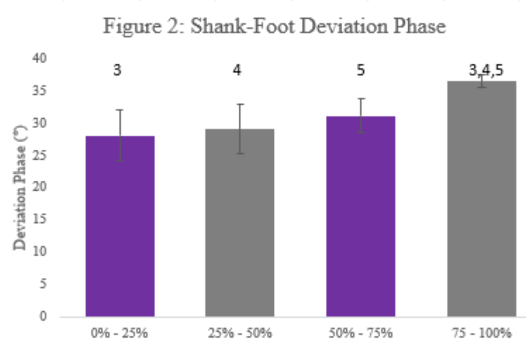
Twelve healthy adults (20±1 years, 6 male, 6 female) completed an incremental cycling VO2max test, which consisted of a 5 min warm-up at 60W, increasing a one-half watt per second until failure. During the test, participants were outfitted with an IMU motion capture system (The MotionMonitor, Chicago, IL, USA) with sensors on the upper torso, pelvis, bilateral thigh, shanks, and feet) and collected at 100 Hz. To analyze and determine the outcome variables, a custom MATLAB program (The Mathworks, Inc., Natick, MA, USA) was developed to determine the CRP ratios of the thigh-shank (TS) and shank-foot (SF) during each trial. Normalized sagittal plane joint angles and velocities (Figure 1) were calculated for the duration of the test to determine CRP_{mean} and the deviation phase (DP) of the TS and SF, The deviation phase was then averaged across the quartiles of each test to account for the varying length in time completion based on the performance of each participant. Therefore, data were analyzed according to the following time periods: Period 1= 0% to 25%, Period 2 = 25% to 50%, Period 3 = 50% to 75%, and Period 4 = 75% to 100% of the trial length. Repeated measures ANOVA assessed differences in thigh-shank DP and shank-foot DP, with Bonferroni post-hoc tests for $p < 0.05$.

RESULTS

Results of the present study indicated a significant time effect for both thigh-shank and shank foot coordination variability (i.e. deviation phase). Specifically, participants exhibited significantly lower ($p < 0.001$) DP during 0% - 25% and 25% - 50% as compared to 75% - 100% time periods (Figure 1). Similarly, participants exhibited significantly lower ($p \leq 0.01$) DP during all time frames (0% - 75%) as compared to 75% - 100% (Figure 2)



1: Thigh-Shank was significanlty ($p < 0.001$) lower during 0% - 25% as compared to 75% - 100%.
2: Thigh-Shank was significanlty ($p < 0.001$) lower during 25% - 50% as compared to 75% - 100%.



3, 4, 5: Shank-Foot was significanlty ($p \leq 0.01$) lower during 0% - 75% as compared to 75% - 100%.

DISCUSSION

The aim of the present study was to examine the change in sagittal plane coordination variability over the course of an incremental cycling test. Results indicate that individuals tend to display greater variability of the lower extremity during the latter stages of the test, when in a more fatigued state, as compared to earlier in the test, when not as fatigued. Furthermore, results suggest that these changes may be a result of changes in the dynamics of the thigh-shank relationship. The results of the present study may be partially explained by the change in pedaling frequency which occurred between the start and end of the trials as pedaling frequency decreases as fatigue develops. These altered movement patterns indicate the relative role of various joint segments in contributing to task execution, particularly in higher-intensity, fatigued conditions.

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Impact of Adjusting Theia3D User Settings on Lower Limb Kinematic Outcomes During Overground Walking in Typically Developing and Children with Cerebral Palsy

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INTRODUCTION

Theia3D (Theia Markerless Inc., Kingston, ON) is a video-based markerless (ML) motion capture system that offers a viable alternative to traditional marker-based (MB) systems for 3D clinical gait analysis (3D-CGA). Using deep learning algorithms to track keypoints from 2D video for pose estimation, it addresses some limitations of MB systems, including marker misplacement, and inter-assessor variability [1]. While promising, Theia3D has varying accuracy in measuring kinematics during walking. In healthy young adults, root mean square differences (RMSDs) were within 5° in the frontal plane and 3.3–6.9° for sagittal knee and ankle angles but exceeded 10° for hip rotation [2-3]. In children with cerebral palsy (CP), our group observed RMSDs exceeding 10° for pelvic tilt, hip flexion/extension, hip rotation, and foot progression [4] consistent with pediatric studies highlighting concerns about Theia3D's knee axis definition and hip rotation [5]. Adjustments to Theia3D's degrees of freedom (DOF) and filter cutoff frequency could alter solution accuracy, but these factors remain understudied and underreported in the literature. DOF settings affect keypoints stability and enable independent tracking of each segment's position and orientation. Higher DOF allows segments to move independently within the kinematic chain, reducing inter-segment influence and compensatory errors. Filter cutoff frequency balances noise reduction and motion detail. Low cutoff frequencies can cause excessive smoothing, leading to underfitting and loss of details, while high cutoff frequencies may result in a jittery skeleton by insufficiently filtering noise. Theia3D's internal studies reported robust kinematic outputs to DOF adjustments, showing significant changes in pelvic and hip movements in the frontal plane when increasing DOF from 3 to 6 (ankle-knee-hip) in healthy adults [6]. However, its relevance to children with CP remains unclear. This study aimed to evaluate the agreement between Theia3D and a MB approach in measuring hip angles (three planes) and sagittal plane angles of the knee and ankle during overground walking in typically developing (TD) and children with CP. Using a multivariate Bayesian regression model, the analysis accounted for group, DOF, and filter cutoff frequency settings.

CLINICAL SIGNIFICANCE

Our findings offer guidance to users on optimizing Theia3D 2023 settings for clinical gait analysis, particularly in children with CP.

METHODS

Thirty-five TD children (17 M, 18 F; 11.7 ± 3.7 years) and 35 children with CP (20 M, 15 F; 12.1 ± 3.9 years; GMFCS I–IV) participated in this study. Participants wore 54 reflective markers on the trunk, pelvis, thighs, shanks, and feet. Data were collected in two labs with synchronized camera systems, each capturing a 5m (L) × 2m (W) × 2m (H) volume at 100 Hz. Lab A used 10 MB cameras (Oqus 500, Qualisys, SE) and 10 video cameras (8 Miqus Hybrid, 2 Miqus Video, Qualisys, SE). Lab B used 12 MB cameras (Kestrel 4200, Motion Analysis Corp, US) and 10 Miqus Hybrid cameras (Qualisys, SE). Video data were processed with Theia3D (v2023.1.0.3161[patch 18]) as detailed in **Table 1** and analyzed in Visual3D (v. 2023.07.2 Student, HAS-Motion, ON) alongside MB marker trajectories to compute 3D joint angles. RMSDs between Theia3D settings and MB were computed in MATLAB (R2021a, Natick, MA). A Bayesian regression model in R (RStudio 2022.12.0) assessed the effects of group, DOF, and cutoff frequency on lower limb joint angles.

Table 1: Analysis settings used in Theia3D for validation testing against marker-based outcomes.

Settings	Knee DOF	Ankle DOF	Cutoff Frequencies (Hz)
1	3	6	5, 10, 15, 20, 25
2	2	3	5, 10, 15, 20, 25

RESULTS

TD children showed lower RMSD for ankle dorsiflexion-plantarflexion (-1.60°; 95% CI: -2.70° to -0.50°) compared to children with CP. DOF-ON significantly reduced RMSD in hip flexion-extension (-0.38°; 95% CI: -0.51° to -0.25°) and hip rotation (-0.72°; 95% CI: -1.12° to -0.32°), while filter cutoff frequency had no influence. Interaction effects, including two- and three-way interactions among group, DOF, and filter cutoff frequency, were insignificant across all joint angles, as the CIs consistently included zero (**Figure 1**).

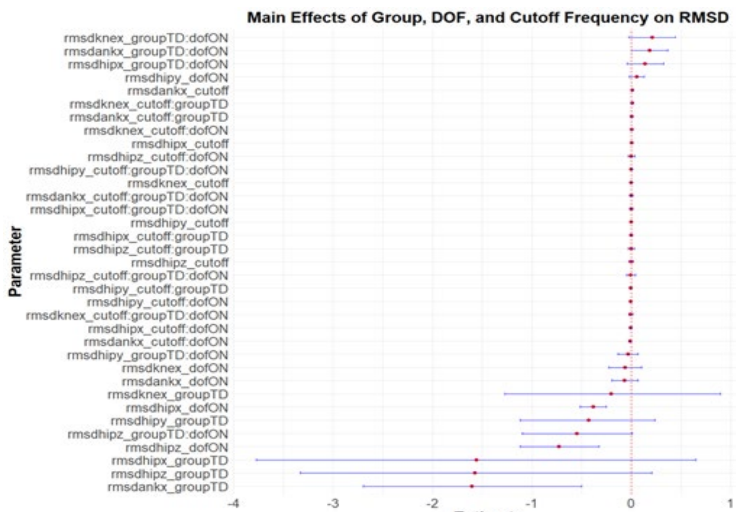

Figure 1: Overview of Bayesian model

DISCUSSION

Group and DOF settings influenced outcomes between MB and ML systems in measuring lower limb kinematics, but filter cutoff frequency did not. Children with CP showed greater RMSD values for ankle dorsiflexion-plantarflexion, consistent with previous studies [7]. Theia3D's dual-segment foot model, which tracks the foot and toes separately, contrasts with the single-segment approach of MB systems. Increasing DOF downstream (ankle and knee) in Theia3D 2023 benefited hip joint predictions and reduced compensatory errors along the kinematic chain, partially supporting Theia3D’s internal findings [6]. The lack of significant interaction effects suggests that DOF and filter cutoff frequency adjustments did not differentially impact kinematic agreement between systems for TD and CP groups.

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DISCLOSURE STATEMENT

The authors declare no conflicts of interest related to this work.

A People-First Gait Analysis Device: Bringing Sensor-Based Gait Assessment into Everyday Care

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INTRODUCTION

We present a novel wearable device for facile and cost-effective gait monitoring in both indoor and outdoor environments. Most medical grade gait analysis devices, such as gait mats or motion capture systems, can provide highly accurate data [1]. However, due to their size, complexity, and limited spatial range, they are not practical for day-to-day gait monitoring. Although some wearable gait monitoring devices exist on the market, they either fail to capture all key gait parameters (e.g., inertial devices) or require patient-specific customization (e.g., instrumented insoles). These complexities discourage clinicians from integrating gait monitoring technologies into routine rehabilitation.

CLINICAL SIGNIFICANCE

The proposed device bridges the "practicality gap" in sensing technologies for routine gait rehabilitation. Designed for both simplicity (*ease of use*) and clinical value (*usefulness*), it features a one-size-fits-all shoe cover paired with an intuitive, guided interface. The device provides clinicians with key spatiotemporal gait parameters, along with approximate ground reaction pressure, in an accessible format. It allows them to compare data from previous sessions to track progress, identify relapses, or evaluate interventions. By making sensor-based gait assessment simple and accessible, this device can become a routine part of clinical visits, enhancing traditional observational assessments in both indoor and outdoor environments.

METHODS

The shoe cover was designed using the following criteria: durability, size adjustability, and ease of donning and doffing. The shoe cover features a two-piece design for adjustability—separate forefoot and heel sections connected by buckles. Made of water-resistant neoprene, it is durable and highly elastic, ensuring a comfortable fit over various shoe sizes.

Each instrumented shoe cover is furnished with nine sensors: one inertial measurement unit (IMU) attached to the instep, one time-of-flight (ToF) distance sensor on the medial side of the foot, and seven force-sensing resistors (FSR) placed in strategic locations to capture approximate ground reaction forces. Temporal parameters are extracted using standard methods based on heel-strike and toe-off timings estimated through FSRs and the IMU [2], [3]. Spatial parameters are determined from 3D estimations of the feet at every timestep using an extended Kalman filter [4]. Unlike other wearable gait devices, which typically overlook step width—a key indicator of balance and fall risk [5], [6]—the proposed device also captures step width and its variability. The Kalman filter is adapted from common pedestrian dead-reckoning (PDR) algorithms, which estimate the acceleration, position, velocity, and orientation [4]. Our algorithm consolidates the data from the ToF sensor with the IMU predictions to correct the step width measurement.

A Wi-Fi-connected graphical user interface (GUI), developed using Python, allows clinicians to create client profiles and administer walk tests. It then provides them with meaningful information including spatiotemporal parameters and interactive plots of approximate ground reaction forces. The GUI also allows clinicians to record their own observations, track progress through historical data, and generate reports.

The proposed gait monitoring device was validated using established gait sensing systems, such as the loadsol by novel inc. [7] and GAITRite [8]. We plan to conduct further testing at the University of Toronto's Winter Lab, validating its durability and performance in harsh weather and challenging outdoor terrains.

DEMONSTRATION

The adjustable shoe cover is shown in Figure 1. The two-piece design enables the FSRs to be placed in the correct relative locations beneath the foot regardless of the shoe size. The shoe cover accommodates a variety of sizes, from a women's US size 6.5 to a men's size 12.

The interface for administering walking tests is shown in Figure 2. It displays detailed instructions and provides visual cues to the clinician and user for standing and walking.

Figure 1: The instrumented shoe cover.

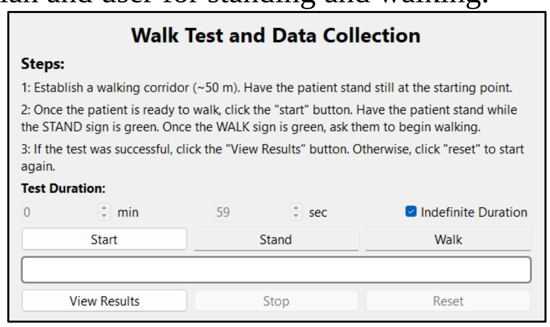

Figure 2: The data collection interface.

SUMMARY

We propose a wearable gait monitoring device and interface that provides an easy and useful way for clinicians to gather informative gait characteristics during routine gait training and assessment sessions. This is facilitated with a durable, size-adjustable device worn over the shoe to collect sensor data. A user-friendly GUI enables clinicians to manage client profiles, conduct walk tests, analyze spatiotemporal data, track progress, and generate reports.

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DISCLOSURE STATEMENT

There are no conflicts of interest associated with this project.

Comparing Spatiotemporal Characteristics of Stepping-in-Place and Overground Walking in Healthy Adults

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INTRODUCTION

Stepping in place (SIP) is commonly used in locomotor training for frail older adults and those with neurological disorders as an alternative to overground (OG) walking [1]. Previous research has shown that OG walking improves strength and lower extremity power [1]. While SIP is typically used for balance training, it also offers a safe way to simulate walking and promote dynamic balance and reactive stability. Though SIP and walking share similar movement patterns [2], they differ in stepping frequency, possibly due to increased stability during double stance [3]. SIP's relationship to walking remains unclear.

Short-term Lyapunov exponents (STLE), a measure of local dynamic stability, have been validated as predictors of fall risk [4]. This study aimed to test if STLE in SIP is correlated with STLE in walking. If such a correlation exists, improvements in SIP could indicate improvements in walking stability.

CLINICAL SIGNIFICANCE

SIP is safer than gait training for populations with high fall risk and perturbed SIP training could prove to be more feasible and safe than perturbed gait training. Understanding how metrics of SIP compare to those of walking will support future exploration of how improving spatiotemporal metrics during perturbed SIP training may transfer to improving walking.

METHODS

Seventeen healthy adults (7 Male, 10 Female) from the Ohio State University community participated after providing IRB-approved informed consent. Participants had to self-identify as able to walk on a treadmill for 60 minutes without pain. Exclusion criteria included uncorrectable visual or auditory impairments, balance deficits, or cognitive impairments.

Participants performed a 5-minute overground walking task followed by 2 minutes of SIP. Five triaxial accelerometers (Trigno Wireless, Delsys, Boston, MA) were worn on the thighs, shanks, and pelvis. Heel strike and toe-off were identified using a modified version of Gurchiek et al.'s algorithm [5]. Mean step time (MST), double-support duration (DSD), and step time standard deviation (SD) were calculated, and STLE was computed using a modified version of Ihlen et al.'s [4] algorithm in MATLAB 2024b (The MathWorks, Natick, MA). Statistical methods included Kolmogorov-Smirnov tests for normality, non-parametric correlations, and Wilcoxon signed-rank tests for differences between conditions.

RESULTS

Several variables violated normality assumptions, so non-parametric methods were applied. Kendall's tau revealed correlations between MST ($p = 0.026$, $\tau = 0.397$) and STLE ($p = 0.048$, $\tau = 0.353$, Fig. 1) in SIP and OG walking. The Wilcoxon signed-rank test showed significant differences in MST (p = 0.01), stepping SD (p < 0.001), DSD (p < 0.001), and STLE (p = 0.002) between conditions (Figs. 1 & 2).

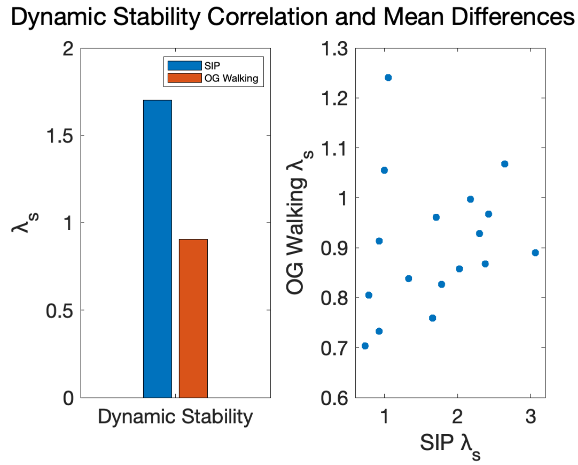

Fig. 1: Dynamic stability measured by short-term Lyapunov exponents correlation and mean differences between conditions.

DISCUSSION

STLE values showed weak correlation between OG walking and SIP, suggesting that the stability requirements of the two activities are different. Walking is often described as "controlled falling," while SIP involves shifting balance between legs. The stability during double stance [3] and the uncommon nature of SIP in healthy individuals may also contribute to the weak correlation. STLE values for OG walking were consistent with existing literature, while SIP results were significantly larger, indicating less dynamic stability during SIP (Fig. 1).

SIP may be less stable, i.e. more variable, than walking, which could be both because of its novelty to the participants in the study as well as the relative lack of visual feedback that one gets during walking from optical flow. SIP demonstrated greater step variability, MST, and DSD, which could be linked to the wider, shorter, and slower steps taken when individuals lose balance [6]. These results potentially support use of SIP as a therapeutic and diagnostic tool with a target of reducing these metrics. Study limitations, including potential effects of visual, auditory, and cognitive impairments, as well as fatigue, suggest areas for future research. Future studies should investigate the impact of specific cues on SIP, explore differences in kinetics and muscle activation, and compare anterior-posterior STLE in OG walking with mediolateral STLE in SIP.

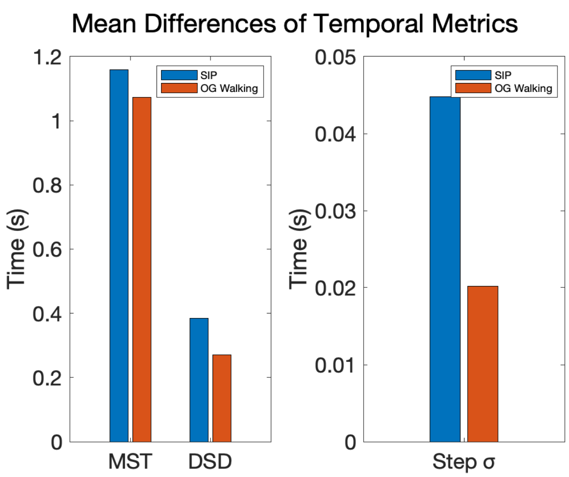

Fig 2. Mean differences of temporal metrics from Wilcoxon Signed ranks test.

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“Row to Grow”: Measuring Kinematic Changes in Gait and Rowing in Adolescents with Cerebral Palsy after Participation in a Rowing Program

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INTRODUCTION

Children diagnosed with Cerebral Palsy (CP) often present with atypical gait and functional limitations that can impact their quality of life and musculoskeletal health. Closed kinetic chain activity for children with CP has been shown to improve gait and functional metrics as well as increase self-reported quality of life measures (1). Rowing, a closed kinetic-chain activity, has been observed in other communities to improve function and quality of life for adolescents with CP (2). There is an incredible opportunity for partnership between Sunny Hill Health Centre, BC Children’s Hospital (BCCH), and the provincial rowing community, to develop accessible rowing programs. Part of the scope of the current study is to investigate the effects of a 3-month rowing program on gait and rowing biomechanics in adolescents with CP.

CLINICAL SIGNIFICANCE

Identifying rowing as an activity that is 1) accessible to adolescents with CP, and 2) can help to improve gait metrics, will be a benefit to the CP population and care provision for adolescents with CP. Investigating how gait and rowing biomechanics both change due to rowing could also help elucidate the gait-improving mechanisms of closed kinetic-chain activities.

METHODS

Prospective participants (GMFCS I-III; n=20 anticipated, 2 cases presented in the current abstract) were identified either during their visit to The Motion Lab at BCCH (TML) for a pre-scheduled gait assessment or from the orthopedic department. Motion capture for all activities was performed using a 12-camera Qualisys marker-based system, with a modified Helen Hayes marker set and single-segment foot model.

Evaluation of the effects of rowing on gait and rowing metrics were by longitudinal comparison; participant data was collected at two time points: 1) ‘Pre’ - at their pre-scheduled gait analysis appointment, and 2) ‘Post’ - upon completion of the rowing program, at the follow-up visit to TML. Training sessions ran for three months (60-90mins/session, 1-2 sessions/week) and included use of an indoor rowing machine and on-water rowing.

In all walking trials, the participants were directed to walk 10m at a self-selected, comfortable speed, until five trials were recorded. Following gait assessment and a rest break, participants were oriented to an indoor rowing machine in TML, outfitted with a load cell (4448N, Omega Engineering) to measure the force used to pull the handle. They rowed for 500m (approximately 2.5-3 minutes), and five consecutive rowing cycles were extracted for analysis. The five gait and five rowing trials were averaged for comparison methods.

Quantitative gait data for comparison included exam-based range of motion (ROM) and strength measures, temporal-spatial gait metrics, representative gait deviation index (GDI) and range of motion (ROM) in the sagittal plane at the hip, knee, and ankle during gait.

Quantitative rowing data included ROM in the sagittal plane at the pelvis, hip, knee and ankle, stroke time, and force-impulse during rowing cycles.

RESULTS

Due to space limitations, a portion of the results for two participants in the study are shown below. Participant 1 (P1) has CP diplegia, GMFCS II and walked with bilateral solid AFOs and participant 2 (P2) has CP left hemiplegia, GMFCS I. P1 saw an improvement in GDI, step length, and velocity bilaterally, while P2 had a decreased GDI and marginal differences in step length and velocity (Table 1). When rowing, P1 showed increased sagittal knee ROM and P2 showed decreased sagittal knee ROM and resolution of knee hyperextension (Figure 1).

Table 1 – Sample gait metrics Pre (green) and Post (red) rowing program for participants 1 and 2.

	Side	GDI		Temporal-spatial Metrics				Maximum Knee Extension at Terminal Swing (Degrees)	
				Step Length (cm)		Velocity (cm/s)			
P1	Right	86.36	92.38	52.56	70.78*	101.44	125.04*	7	-2
	Left	90.90	101.23	55.28	64.43*			14	5
P2	Right	101.21	89.90	56.52	56.88	113.49	114.82	1	0
	Left	95.78	85.07	57.59	59.05			0	-2

*Change of more than one standard deviation (from typically developing population) for temporal-spatial metrics

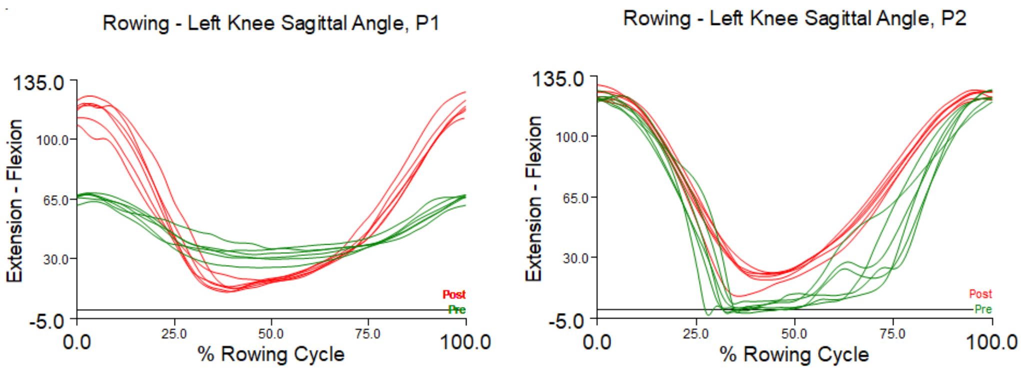

Figure 1 – Sample left knee sagittal angles during rowing stroke. Participant 1 (left) and Participant 2 (right) at Pre (green) and Post (red) rowing program timepoints.

DISCUSSION

Motion capture methods enabled quantification of the kinematic gait and rowing changes observed when adolescents with CP participated in a rowing program. Sagittal plane kinematics showed increased knee ROM while rowing for one participant which may have contributed to their increased maximum knee extension in terminal swing during gait. The two participants may not be representative of all participants and future work will look at the variability and trends across 20 participants. This work prompts further investigation into the utility of closed kinetic-chain activities, like rowing, to improve gait biomechanics in adolescents with CP.

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DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

The Effect of Aquatic Environment and Speed on the Co-Contraction of Lower Limbs Muscles in Cerebral Palsy Children

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INTRODUCTION

Co-contraction, the simultaneous activation of opposing muscles around a joint, enhances mechanical joint stability, enabling controlled and precise movement. In children with cerebral palsy (CP), muscle spasticity can impact co-contraction, affecting gait and motor function.[1] The co-contraction index (CCI) serves as a valuable metric for quantifying muscle co-contraction and estimating joint stiffness, offering a less invasive alternative to traditional clinical measurements.[2] Among rehabilitation therapies for children with CP, treadmill training and aquatic therapy have been identified as particularly effective in improving gait. [3] An aquatic treadmill potentially combines the qualities of both therapies. To our knowledge, this study would be the first to explore standard and aquatic treadmill environments with speed modulation by investigating how these variables affect CCI in the CP population.

CLINICAL SIGNIFICANCE

This preliminary study compares walking on a conventional treadmill with walking on an aquatic treadmill to improve our understanding of muscle control during common rehabilitation interventions for children with CP. We hypothesized that increasing treadmill speed will increase CCI values and that the aquatic environment will reduce CCI in the lower limbs. These results may be beneficial to rehabilitation interventions targeting neuromotor control pathways.

METHODS

Eight children with CP (6–18 years, GMFCS Levels I-II, with a fixed knee flexion deformity exceeding 10°) took part in this pilot study. Participants performed three 3-min walking trials on both a conventional treadmill (Dry) and an aquatic treadmill (Wet) with the water level set to the participant's xiphoid process. This submersion level is suggested as optimal for aquatic gait therapy with weight offloading in prior work with adult subjects.[4] The participants' self-selected walking speed was determined using a previously defined approach[5] for each treadmill separately, and participants walked at 75 % (Slow), 100 %(Normal), and 125 %(Fast) of their self-selected speed. Participants were instrumented bilaterally with waterproof wireless surface electromyography (EMG) equipment on their tibialis anterior (TA), medial gastrocnemius (MG), rectus femoris (RF), and semitendinosus (ST) muscles. Waterproof IMUs on the feet, shanks, thighs, and pelvis were used to determine gait events of initial contact for stride identification. EMG data were processed using a custom MATLAB program to compute CCIs using the index (EMGS/EMGL) × (EMGS+EMGL).[2] This CCI approach defines EMGS as the less active muscle and EMGL as the more active muscle for each frame of data. The larger the resultant CCI, the more co-contraction the limb is experiencing.[2] Only left leg data, regardless of limb dominance or impairment, was used due to equipment malfunctions affecting several right leg trials. A two-way repeated measures ANOVA was calculated in SPSS to determine differences in CCI values amongst RF/ST and TA/MG muscle pairings at different conditions and speeds.

RESULTS

There was no statistically significant two-way interaction between condition and speed (F (2,14) =0.717, p > 0.05). The main effects of condition and speed indicated that CCI values for both muscle pairs increased (10-15% between Slow and Normal speeds and 11-33% between Normal and Fast speeds) and were 11- 35% higher in the Dry condition (Table 1). The ankle TA/MG pairing had the only statistically significant results with p-values of <.001 for speed and 0.045 for condition. All changes in speed and condition have large effect sizes.

Table 1 Mean CCI values with Standard Error (SE) and statistical parameters for Ankle (TA/MG) and Knee (RF/ST) muscle pairings.

	TA/MG Pairing				*RF/ST Pairing*			
	Mean (SE)	F	p	ηp^2	Mean (SE)	F	p	ηp^2
Speed		F(2,14)= 21.431,	p <.001*	**0.75**		F(2,14)= 1.939,	p =.181	**0.22**
Slow	.220(.032)				.290(.060)			
Normal	.242(.035)				.302(.053)			
Fast	.298(.043)				.333(.039)			
Condition		F(1.7) =5.721,	p =.048*	**0.45**		F(1,7)= 1.562,	p = .252	**0.18**
Wet	.216(.032)				.259(.085)			
Dry	.291(.046)				.358(.029)			

* Statistically Significant. Large effect sizes are bolded.

DISCUSSION

These preliminary findings suggest that lower limb co-contractions in children with CP increase with treadmill speed, indicating stiffer joints at higher speeds across both treadmill conditions. Reduced co-contractions in the aquatic environment likely result from buoyancy and bodyweight offloading. The effects of speed and condition were more pronounced in the TA/MG muscle pairing, partially contradicting a previous study where CCI values increased at the ankle in water.[6] However, we speculate this was due to that study being overground walking rather than treadmill walking. The RF/ST pairing showed the same trends but not to a significant degree. Study limitations include a small sample size, with ongoing efforts to expand the dataset. Future research should explore multiple CCI calculations, optimal self-selected walking speeds, and ideal water levels for underwater treadmill training in children.

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DISCLOSURES

We have no conflicts of interest to disclose.

Revisited: GCMAS Podium/Poster Publication Rates—
Did the COVID-19 Pandemic Impact Our Scientific Dissemination?

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Introduction

Each year there are approximately 1.5million citations added to PubMed.[1] During the COVID-19 pandemic citations rose from 1.36M in 2019, reaching a maximum of 1.73M in 2021. As reported at the 2019 Gait and Clinical Movement Analysis Society (GCMAS) meeting, approximately 40% of presentations at the annual meeting between 2011 and 2018 had been published. The goal of this investigation was to reassess GCMAS publication rates during the COVID-19 pandemic.

Clinical Significance

The mission of the GCMAS is to "improve functional outcomes and quality of life for individuals with any movement disorder at any age. We apply the latest technology and professional knowledge to measure, evaluate and understand human movement…" This knowledge should be shared with the scientific and medical community outside of our society through publication in peer-reviewed journals.

Methods

From 2011 to 2024, titles and authors of each accepted abstract were identified as a podium or poster presentation from the GCMAS meeting proceedings. GCMAS does not keep formal documentation of abstract scoring results, therefore, non-accepted abstracts were not available for review.

Publication was defined as a full-length (or short communication) manuscript appearing in a journal that uses a process of peer-review. To determine whether a presented abstract had been published, a multi-step computerized PubMed search was conducted using the full title of the presentation, key words from the presentation title. and presenter name. If no publications were found, the search was repeated with other authors listed on the abstract. The titles of potential publication matches were compared with the original title of the presentation. In instances where authors and/or titles differed between the GCMAS presentation and publication, the abstract of the publication was reviewed to determine if it matched the GCMAS presentation. No attempt was made to identify or track multiple articles arising from a single abstract. In addition, a single publication could be linked to multiple GCMAS abstracts. For published articles, the date of publication, journal title, session of presentation, and journal impact factor, determined using InCites Journal Citation Reports for the article publication year (https://clarivate.com/products/journal-citation-reports/) was recorded. For articles published in 2024, the most recent (2023) impact factor was used. Time to manuscript publication was calculated relative to the date of presentation at the annual GCMAS meeting.

Results

There were 1571 abstracts included in this investigation, presented between 2011 and 2024. Of note, the 2020 GCMAS meeting was cancelled due to COVID-19 and the 2021 & 2022 meetings were virtual. On average, each year 46% of all accepted GCMAS presentations were podium presentations (range: 35-62%).

Publications were identified for N=626/1570 (40%) presentations. There were 44 publications which were matched to more than one abstract, resulting in 582 unique publications. The average publication rate from 2011-2023 was 50% (range: 34-66%) for podium presentations, and 35% for posters (range: 14-50%). The highest publication rage was for the 2021 virtual meeting, with an overall 51% publication rate (66% for podiums and 43% for posters, Figure 1).

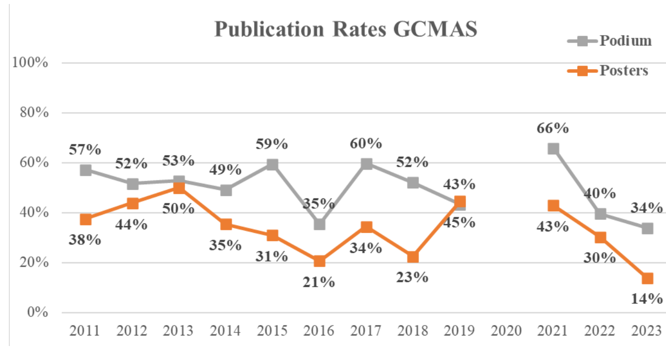

Figure 1: The highest GCMAS publication rate was for the 2021 virtual meeting.

The mean time to publication was 1.4 ± 4.9 yrs (range: -3 [published prior to presentation] to 7.6 yrs, Table 1). The average journal impact factor was 2.443 ± 1.194 (range: 0.574-16.710). A journal impact factor was not available for 53 publications (journal not indexed/score not available for the publication year on InCites Journal Citation Report). Mean time to publication was slightly less, and journal impact factor was slightly increased for podium presentations compared to poster presentations.

Table 1: Mean time to publication was slightly less and journal impact factor was slightly increased for podium presentations compared to poster presentations

	Mean Time to Publication (yrs)	Average Impact Factor
Overall	1.4 ± 4.9	2.443± 1.194
Podiums	1.6 ± 6.4	2.535± 1.127
Posters	1.5 ± 1.7	2.326± 1.268

Discussion
Approximately 48% of GCMAS abstracts made it to publication in PubMed indexed journals. During and following the pandemic, many clinical researchers experienced reduced recruitment in prospective research and had more ‘down’ time to work on publications. While not drastic, GCMAS did experience a slight increase in publication rates from the 2021 meeting. GCMAS initiatives to increase publication, such as educational writing workshops for students and junior researchers, may expand the reach of the work presented at GCMAS through scientific dissemination. Further work is necessary to expand the search to other search engines and databases, which may identify additional published work. This may include Embase, Google Scholar and/or other nonmedical scientific citation databases.

References
[1] MEDLINE PubMed Production Statistics, retrieved on February 3, 2025. [2] All GCMAS proceedings from 2011 through 2024. [3] Citation information for all 1571 manuscripts identified, as well as countless additional manuscripts/abstracts reviewed during the identification process.

Acknowledgement
The authors would like to acknowledge Rinu Daniels for her work on this project in prior to the 2019 GCMAS presentation.

Disclosure
KTF is a 2025 GCMAS conference co-chair.

Assessing Quality and Readability of Clinical Gait/Motion Analysis Laboratories in the US: Are Families Getting the Right Information?

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INTRODUCTION

In this digital age, the first place many patients turn to for information is the internet. Readily available from any smart phone, hospital websites should contain enough information, especially for unique procedures such as clinical gait analysis (CGA), so that patients can be informed prior to their appointment. While the average reading skill of US adults is at the eighth-grade level, the American Medical Association (AMA) and the National Institutes of Health (NIH) recommend a readability level at the sixth- grade level for patient education materials. The purpose of this study was to evaluate readability of CGA websites for both quality (content/information provided) and readability.

CLINICAL SIGNIFICANCE

It is imperative that the online patient education materials and digital footprint of CGA laboratory websites are at the highest quality while maintaining a low readability grade-level to assure health literacy and promote the important services they provide to patients.

METHODS

A list of accredited labs was identified from the Commission for Motion Lab Accreditation (CMLA) website (CMLAinc.org). An additional four non-accredited labs were identified from the GCMAS "Find-a-Lab" website (gcmas.org). The quality of information on each site was ascertained based upon key information on clinical motion capture, with a maximum score of 14pts. This included items such as the definition of CGA, list or discussion of key components of CGA, patient populations who may benefit from a CGA, clinical and technical staff involved in CGA (general explanation, not specific people), and an explanation of how the results may be used by the referring physician, including potential recommendations provided by CGA. Readability was assessed using the Flesch-Kincaid reading ease and grade level. In addition, the word count and words per sentence were also determined. In some circumstances, minor edits were made to website text – for example, bulleted lists were edited to include a period after each sentence for accurate word count determination. Descriptive summary statistics were determined for all sites, as well as between CMLA accredited and non-CMLA laboratories.

RESULTS

Overall, the mean quality score was 10.4 ± 2.7. Most websites had good descriptions of CGA, its use in certain patient populations, and how it is used in treatment decision making. The scores were less consistent within potential recommendations. Few sites mentioned anything about potential insurance coverage and/or costs involved with CGA. Interestingly, several labs had limited contact information for patients and/or potential referring providers on their website.

No laboratory website had a FK grade score at or under an eighth-grade-level. The average FK grade-level for all labs was 10.9 ± 1.0 and ranged from 9.6 – 13.4 [college level].

Overall, there were minimal differences between CMLA accredited and non-accredited lab websites, with only the total word count being significantly shorter on the non-CMLA labs sites.

Table 1: Quality Score Metrics (maximum score of 14, mean±stdev)

	All (n=17)	**CMLA (n=13)**	**Non-CMLA (n=4)**
Quality Score (max 14)	10.4 ± 2.7	10.2 ± 3.0	11.3 ± 1.6
Has clinical website	97%	96%	100%
Definition of CGA	88%	85%	100%
Describe components of CGA (physical exam, mocap, EMG, 3pts)	88%	87%	92%
Describes clinical and technical staff involved in CGA	76%	69%	100%
Instructions on what to bring	76%	77%	75%
Describes length of appointment	76%	77%	75%
Describes potential clinical populations	82%	77%	100%
Describes how CGA can be used by referring provider	88%	85%	100%
Describes potential recommendations from CGA (PT, orthotics, medication, surgery, 2pts)	59%	56%	69%
Discussion of insurance coverage	6%	8%	0%
Lab contact information (for both patients and referring providers, 1pt)	71%	73%	63%

Table 2: Readability of US Clinical Gait Lab Websites (mean±stdev [range])

	All (n=17)	**CMLA (13)**	**Non-CMLA (4)**
Word Count	811 ± 421 [193-1723]	885 ± 442 [193-1723]	569 ± 248 [346 - 826]
Words/Sentence	14.1 ± 2.5 [10 – 21.2]	14.1 ± 2.9 [10 – 21.2]	14.1 ± 0.9 [13.0 - 15.4]
FK Reading Ease	42.0 ± 8.7 [26.4 – 55]	42.0 ± 8.7 [26.4 – 55]	42.0 ± 10.0 [31.0 - 53.5]
FK Grade Level	10.9 ± 1.0 [9.6 - 13.4[]	10.8 ± 1.0 [9.6 - 13.4]	10.8 ± 1.3 [9.6 - 12.4]

DISCUSSION

Prominent clinical gait analysis laboratories have websites aimed at patients, which are well above the recommended sixth-grade reading comprehensive level. To assure equity in health literacy, hospitals should consider reviewing and editing the text on their CGA websites. The addition of short video explanations and graphics, which were not assessed as part of this study, may also provide patient families with additional helpful information.

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DISCLOSURE STATEMENT

KTF is the 2025 GCMAS conference co-chair.

The effects of subsensory electrical noise stimulation on the compensatory reactions during support surface perturbations

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INTRODUCTION

The ability to effectively respond to balance perturbations is crucial for fall prevention [1, 2]. While subsensory electrical stimulation (SES) applied to the skin has been shown to improve proactive balance control, its effects on reactive balance control remain unclear [3]. This study aimed to investigate the efficacy of SES in enhancing reactive balance control in response to unpredictable support surface perturbations and to compare the effects of SES applied to the trunk versus the lower legs.

CLINICAL SIGNIFICANCE

Enhancing reactive balance control through SES may improve postural stability and reduce fall risk [4]. Identifying the optimal stimulation location could inform rehabilitation strategies for individuals with balance impairments.

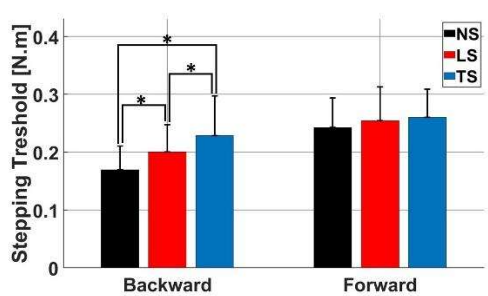
METHODS

Twenty-three young adults stood on a treadmill while recovering from 15 forward and 15 backward surface translations of increasing magnitude to determine the backward and forward stepping thresholds (BSTh and FSTh). Then, they recovered from three repetitions of forward and backward perturbations of fixed magnitude to determine the characteristic of the compensatory step (i.e., step time, step length, step delay and Margin of Stability - MOS). Each test was conducted with no stimulation (NS), leg stimulation (LS), or trunk stimulation (TS) equal to 90% of the sensory threshold. Repeated-measures ANOVA and Tukey post-hoc tests were used to analyze the main and interaction effects of stimulation and repetition.

RESULTS

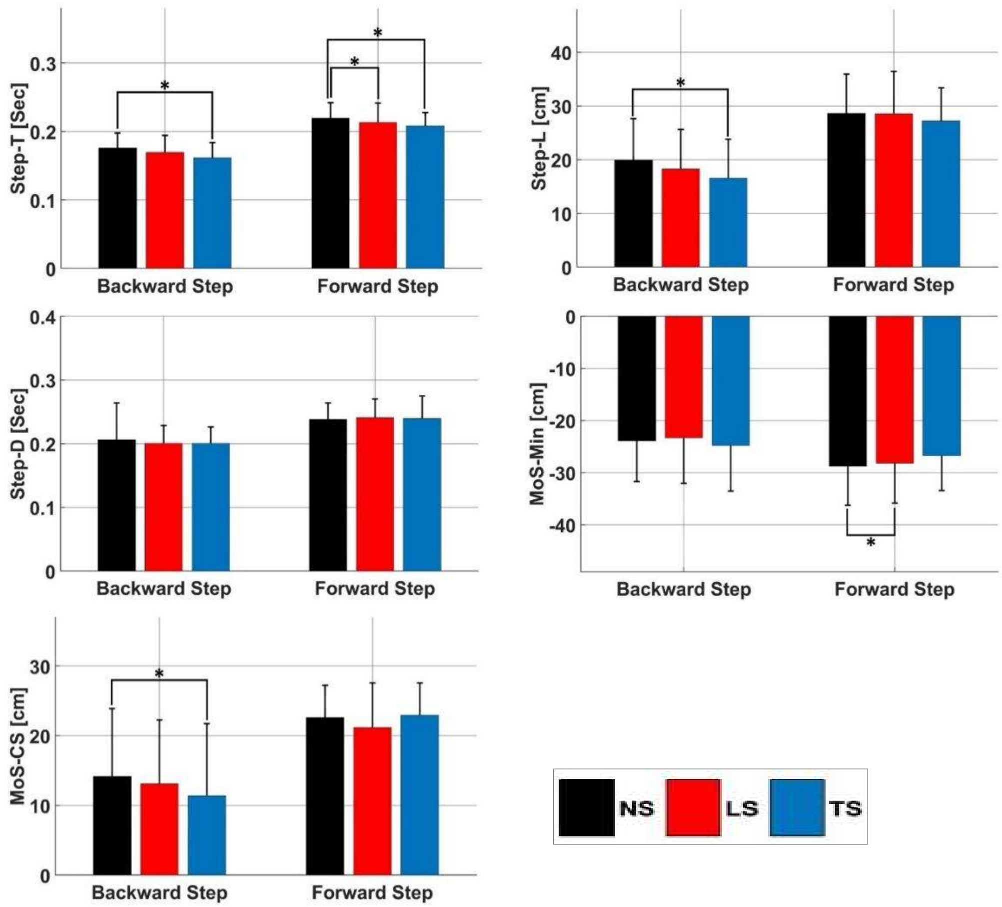
TS and LS increased the BSTh by 31.5% ($p=0.002$) and 16.4% ($p=0.028$), respectively, with greater effects of TS; (ii) during backward perturbations (Figure 1).

Figure 1 - Mean and standard deviation of the Stepping Threshold measures. Outcome measures: *Backward and Forward* stepping threshold (STh). * Symbols indicate a significant difference ($p<0.05$) in the Tukey post-hoc test. To remove the influence of body size, the STh was normalized to $(\text{mass} \times \text{leg} \times \text{g})^{-1}$.



TS reduced compensatory step time by 9.0%, step length by 17.1%, and MOS at compensatory heel strike by 17.7% ($p<0.016$); and (iii) during forward perturbations, LS and TS reduced the step time by 4.5% and 3.5% ($p<0.017$), and increased the minimum MOS by 7.8% and 4.5%, respectively ($p<0.048$) (Figure 2).

Figure 2 - Mean and standard deviation of the spatiotemporal **measure.** Outcome measures: *Step-T* (Step Time), *Step-L* (Step Length), *Step-D* (Step Delay), MOS_{MIN} (Minimum value of Margin of Stability) and MOS_{CS} (Margin of Stability at Compensatory Step). Experimental conditions: No Stimulation (NS), Leg Stimulation (LS), and Trunk Stimulation (TS). * Symbols indicate a significant difference ($p<0.05$) in the Tukey post-hoc test.



DISCUSSION

This is the first study to examine the effects of SES on reactive balance control during support surface perturbations. TS was more effective than LS in enhancing backward reactive stepping responses. These findings suggest that TS may be a promising strategy for improving balance recovery and reducing fall risk in individuals with impaired postural control.

ACKNOWLEDGEMENTS

The authors thank the study participants and colleagues for their support.

DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

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BALANCE ON SINGLE AND INFINITE AXES PASSIVELY UNSTABLE SURFACES WITH INTACT AND BLURRED ACUITY

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INTRODUCTION

Many recreational, occupational, or functional tasks can involve standing on a passively unstable surface (PUS), i.e. one that moves in response to motion of a person standing on it [1,2]. Such characterization inherently excludes devices with externally controlled movements, e.g. perturbation platforms, but can include standing surfaces of both rigid and flexible nature. Among rigid surface PUSs, surface rotational motion can be constrained to occur about a single axis (e.g. skateboard), or have potential to occur about infinite axes (e.g. small boat). Tilt boards (single axis) and wobble boards (infinite axes) are particular examples of rigid surface PUSs, commonly used in training and rehab environments, that differ in rotational constraint.

While balance maintenance can utilize multiple modes of sensory information, visual input has exhibited substantial influence in maintaining balance on rigid surface PUSs. In particular, imposing visual blur has led to increased movement of infinite rotation axes PUSs (e.g., wobble boards, BOSU balls), while persons stood on them with instruction to keep them as still as able [2]. Imposed visual blur has also been associated with increased body segment motion, as characterized by mean segment angular velocities [2].

Balance maintenance on tilt boards and wobble boards, and impact of imposed visual impairment on such balance has been commonly investigated. However, direct comparisons between these PUSs, in conjunction with imposed visual blur has not been explored. Subsequently, the objectives of this study were: to determine effects of rigid surface PUS type (PT) on PUS balance maintenance, as well as impact of visual acuity (VA) with these PUSs.

CLINICAL SIGNIFICANCE

Knowledge, sought by this study, may inform how to differentially manage PUS balance expectations on single axis and infinite axes rigid surface PUSs, and inform regarding impact of impaired visual acuity when standing on such PUSs.

METHODS

Ten healthy males, with age, height, and weight of 24.4±3.5 years, 182.9±7.6 cm, and 828.7±183.3 N, participated after signing an IRB approved informed consent form. Each participant performed balance task trials on a tilt board (TB, single axis PUS) and a wobble board (WB, infinite axes PUS), with clear visual acuity (CL) and blurred acuity (BL, imposed by donning eyeglasses with high refractive lens). For all trials, subjects were directed to keep the PUSs as still as able for 45 seconds. Trajectories of reflective markers, placed on the PUS rigid surfaces and on subject body segments, were obtained with an optoelectronic motion tracking system (Qualisys) at 100 Hz. For each sampling frame, angular velocity of PUS board surface (ω_{bd}), and tilt angle (θ), between surface normal and global vertical vectors, were determined. Mean of ω_{bd} ($\overline{\omega}_{bd}$) and standard deviation of θ (SD_{θ}) were computed as balance task performance metrics, i.e. execution of instruction to keep the PUS rigid surface still. Mean body segment angular velocities were computed for the trunk, pelvis, upper arms and lower arms ($\overline{\omega}_{tr}$, $\overline{\omega}_{pel}$, $\overline{\omega}_{ua}$, $\overline{\omega}_{la}$) to assess balance task strategy.

RESULTS

For the balance performance metrics, $\overline{\omega}_{bd}$ was significantly greater with WB than TB, while SD_{θ} was significantly higher with TB (Fig 1). Both SD_{θ} and $\overline{\omega}_{bd}$ were significantly greater with BL than CL. Among strategy metrics, $\overline{\omega}_{pel}$, $\overline{\omega}_{ua}$, $\overline{\omega}_{la}$ were significantly greater with WB than TB, and significantly greater with BL than CL (Fig 1). For the trunk, $\overline{\omega}_{tr}$, was significantly greater with the WB, but was not significantly affected by acuity (Fig 1). A significant PT/VA interaction was seen for $\overline{\omega}_{bd}$ and $\overline{\omega}_{la}$ (Fig 2). For both of these, increase with blur was statistically more pronounced with WB (Fig 2).

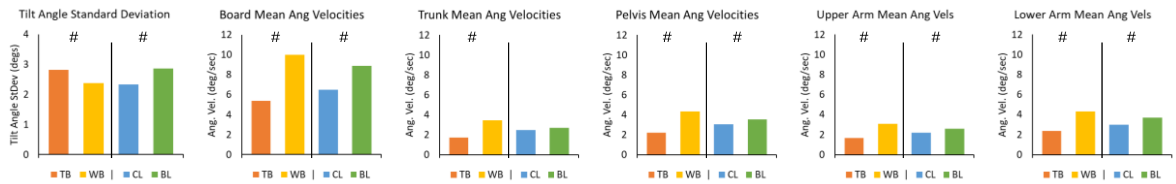

Fig 1. Main effects of PUS Type (TB, WB) and Visual Acuity (CL, BL) on PUS surface-based and body segment-based metrics (# significant main effect, $p < 0.05$).

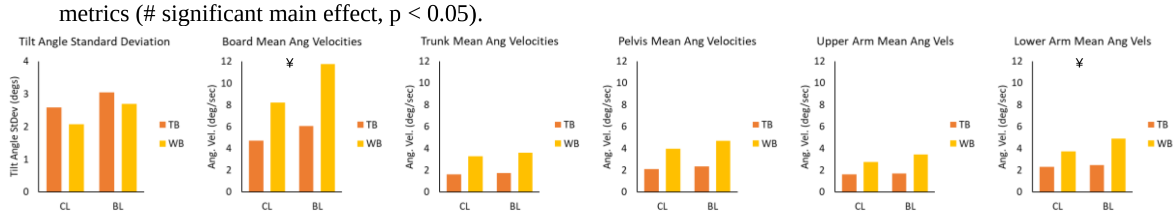

Fig 2. PUS Type/Visual Acuity (PT/VA) interaction effects on PUS surface-based and body segment-based metrics (¥ significant PT/VA interaction effect, $p < 0.05$).

DISCUSSION

Dissimilar effects of PT on SD_{θ} and $\overline{\omega}_{bd}$ (balance performance metrics) indicate that these metrics are likely characterizing different aspects of balance performance (keeping standing surface as still as able). Standard deviation of θ is related to range of PUS surface rotational position. With a single rotation axis PUS, range of tilt angles will generally span to zero, when a surface normal vector approaches being parallel to a global vertical vector. However, such constraint on tilt angles is not inherent with an infinite rotation axes PUS, for which a surface normal vector can substantially avoid alignment with a global vertical. Conversely, $\overline{\omega}_{bd}$ relates to rate of rotational position change, regardless of the range of orientation change. Significantly greater values of both performance metrics with BL, indicates that both range and rate of PUS surface rotational position are adversely impacted by impaired acuity. The interactions that exhibited significance indicate that negative impacts of impaired acuity are more difficult to overcome with an infinite axes PUS.

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DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose

Evaluating Postural Control in Prune Belly Syndrome with the Timed Up and Go Test

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INTRODUCTION

Prune belly syndrome (PBS) is a rare and medically complex congenital myopathy characterized by deficient or absent ventral abdominal wall skeletal musculature, urinary tract distension, and intra-abdominal testes [1, 2]. PBS severity ranges from mild to lethal, with a phenotypic spectrum of abdominal wall weakness and laxity often managed surgically. PBS ventral abdominal wall is most deficient in musculature centrally, whereas it may be normal laterally. 60-75% of individuals with PBS present other abnormalities and orthopedic abnormalities range in incidence from 30-45%, including clubfoot, hip dysplasia, and congenital scoliosis (4%) [3, 4, 5].

Patients with PBS have reported difficulty with balance and a delayed independent ambulation [6]. There is limited understanding of the functional mobility limitations and compensatory movement patterns in individuals with PBS with or without static or dynamic abdominoplasty

CLINICAL SIGNIFICANCE

Evaluating postural control during the Timed Up and Go (TUG) could help identify key adaptations and biomechanical challenges associated with PBS, such as mobility, balance impairment, or increased fall risk. These findings could inform tailored therapeutic approaches, surgical interventions, and rehabilitation strategies to improve functional outcomes and quality of life for those affected by PBS.

METHODS

This study utilized 3-D motion capture and force plate technology to assess movement biomechanics in individuals with PBS during the TUG. Seven patients (age 7-34 years old, 86% male) with PBS were enrolled in this study and completed a one-time visit to a motion analysis lab. Abdominoplasty status included static (n=2), dynamic (n=1), no surgery (n=3), and unknown (n=1). Fourteen typically developing (TD) controls were recruited for comparison (age 9-35 years old, 71% male). Participants completed the TUG test three times with rest between trials as needed to prevent fatigue. The Wilks multi-segment spine model was used to evaluate thoracic spine motion relative to the lumbar segment, lumbar motion relative to pelvis, and pelvis motion relative to the lab. Non-parametric data was analyzed using a Mann-Whitney U test and Spearman's rank-order correlation coefficient.

RESULTS

The total time to complete the TUG was significantly longer in the patients with PBS (9.5 ± 1.0 s) compared to the control group (8.4 ± 1.2 s, $p=0.038$). The difference in time between the initiation of gait and vertical trunk position did not show a statistically significant difference between groups ($p=0.968$). However, it is worthwhile to note that all but one of the control participants initiated walking prior to their trunk reaching its peak vertical position whereas nearly half of the PBS group began gait after their trunk reached peak vertical position.

The ROM across different spinal segments and planes showed no significant differences between the control group and PBS group during the sit-to-stand or stand-to-sit transitions. During the sit-to-stand transition, the lumbar segment had a more flexed starting position (control, 18.4° ± 12.2; PBS, 7.8° ± 2.5; $p=0.044$), average position (control, 17.2° ± 11.0; PBS, 7.5° ± 2.9; $p=0.01$), and maximum angle (control, 28.0° ± 11.7; PBS, 16.9 ± 4.9; $p=0.01$) relative to the pelvis in the PBS group than the control group. The stand-to-sit transition displayed no differences between the control and PBS groups in the starting, ending, average, maximum, or minimum positions in any segment of the trunk or pelvis in any plane ($p>0.05$).

DISCUSSION

Individuals with PBS showed no differences compared to controls in range of motion of their overall trunk, pelvis, thoracic, or lumbar segments during the standing or sitting transitions. There were also no differences in the vertical acceleration of their trunk during these transitions. This may indicate that the PBS group can demonstrate good trunk control during sit and stand transitions, where postural instability is often seen. As they are displaying good postural control, there are no compensations seen in the spine kinematics to assist or control the assent or descent of the body during these tasks. However, the limited differences observed may be attributed to compensations in trunk muscle activation. These compensations, which are not immediately visible in the spine's movement, should be further evaluated to gain a more comprehensive understanding of the individual's movement patterns. The PBS group did take longer to complete the TUG, which may indicate decreased balance and mobility compared to the controls. Although the sample size was small, nearly half of the patients with PBS completed the standing transition prior to initiating gait, whereas all but one control began walking prior to their trunk reaching maximum vertical position. This could indicate that although major functional deficits are not seen during the TUG, there still may be underlying instability requiring completion of standing and a slight delay before they are steady enough to begin walking.

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DISCLOSURE STATEMENT

Kirsten Tulchin-Francis is a board member of GCMAS.

Neck and Shoulder Kinematics During Seated Computer Work in Women with Chronic Neck Pain

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INTRODUCTION

Chronic neck pain is a leading cause of disability, affecting females more frequently and with lower resolution rates than males [1]. It is often linked to prolonged static positions, such as seated computer work [2]. Ergonomic standards for seated computer work provide recommendations that aim to prevent pain through the minimization of neck muscle activity and biomechanical stress. These recommendations include adopting a neutral neck position with one's head upright and ears directly over the shoulders and a forward gaze to the monitor (rather than a right or left angled view). Recently, we discovered that these recommendations do not necessarily reduce upper trapezius (UT) and sternocleidomastoid (SCM) activation and elasticity, and that chair recline must also be considered when determining the optimal ergonomic position. Specifically, we have shown that reclining the chairs back 25° may beneficially impact head and neck kinematics and UT and SCM muscle elasticity [3]. However, these previous findings neglect to consider the impact of chair recline on shoulder kinematics and the influence this may have on shared musculature between the neck and shoulder. This study addresses this limitation by assessing the influence of chair recline on neck and shoulder kinematics during seated computer work in females with and without chronic neck pain.

CLINICAL SIGNIFICANCE

Chronic neck pain, often linked to prolonged seated computer work, disproportionately affects females [1]. Chair recline holds potential to reduce neck muscle strain, but its impact on the kinematics of the entire upper extremity remains unclear. The results of this pilot research indicate that optimizing chair recline during seated computer may assist in improving neck position but could have consequential effects on shoulder kinematics by increasing scapular protraction and elevation. The findings provide preliminary evidence of the safety and effectiveness of recline as an ergonomic adjustment for better workplace design and musculoskeletal health.

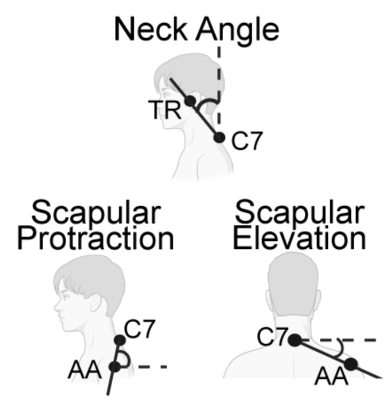

Figure 1: Landmarks used to calculate neck angle, shoulder protraction, and scapular elevation. Abbreviations are for the 7th cervical vertebrae (C7), tragus (TR), and acromion angle (AA).

METHODS

Six female participants (mean (SE): age: 42.5 (6) years, height: 1.7 (0.02) m, weight: 73.5 (4.1) kg) participated in this study. Before the experimental procedures, each participant completed the Neck Disability Index (NDI). One participant was categorized as having no disability due to neck pain, 3 participants had mild disability due to neck pain, and 2 participants had moderate disability due to neck pain. Motion capture markers were placed on the seventh cervical vertebrae (C7) and bilaterally on the tragus (TR) and scapular acromion angle (AA). Participants were seated at a standardized computer workstation while seatback recline was systematically altered. Three recline angles (0° (e.g., no recline), 12.5°, 25°) were presented in random order and the participants self-selected their head and neck posture in each recline angle. Each posture was held for ~4 minutes while motion data were collected. The relationship between NDI and neck, scapular protraction, and scapular elevation angles **(Figure 1)** were derived using Spearman correlations. Significance was set at $\alpha=0.05$.

RESULTS

There were no significant relationships observed between NDI and neck and shoulder kinematics during the 0° recline level (all $p>0.182$). At 12.5° recline, NDI was significantly correlated with scapular protraction ($r=-0.730$, $p<0.001$) and scapular elevation ($r=-0.575$, $p=0.01$), with greater disability due to neck pain being associated with greater scapular protraction and elevation in this position (**Figure 2**). At 25° recline, NDI was significantly correlated with neck angle ($r=0.717$, $p<0.001$) and scapular protraction ($r=-0.424$, $p=0.039$). In this position, greater disability due to neck pain was associated with greater neck flexion and scapular protraction.

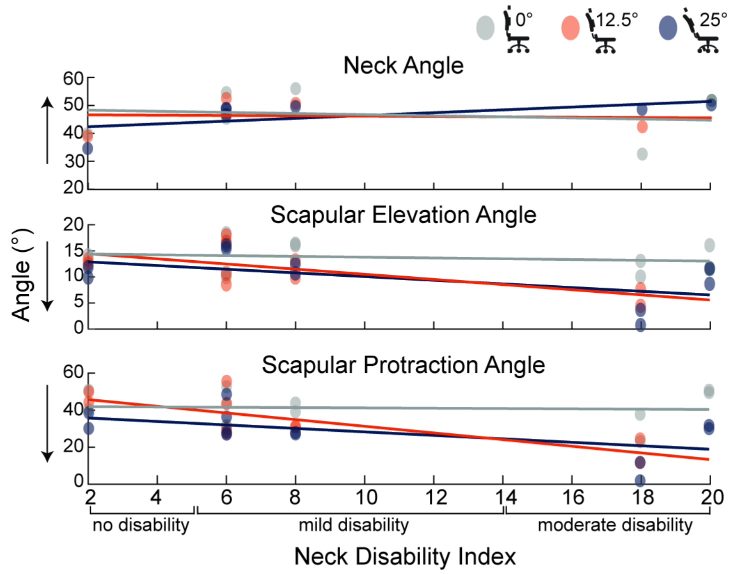

Figure 2: Neck and shoulder kinematics during chair recline at 0° (gray), 12.5° (orange), and 25° (blue), with least-squares lines of best fit for each condition. Transparent dots represent individual data points. Arrows on the left indicate the direction of increasing neck flexion, scapular elevation, and scapular protraction, respectively.

DISCUSSION

These kinematic adjustments may reflect a compensatory strategy to maintain visual alignment and access to the keyboard and mouse during reclined seated computer work. However, the postural changes can either be supported by the chair or require muscular effort. Changes supported by the chair are likely less problematic than those relying on muscle contraction, which may increase strain and activation. Optimizing chair recline during seated computer work may assist in improving self-selected neck position but could have consequential effects on shoulder kinematics, including increased scapular protraction and elevation. Our forthcoming research examines the relationship between neck and shoulder kinematics, muscle activation, and muscle elasticity during these tasks to assess their role in musculoskeletal demands during seated computer work.

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DISCLOSURE STATEMENT

We have conflicts of interest to disclose.

Comparison of Static Alignment and Segmental Foot Kinematics

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INTRODUCTION

Segmental foot models are widely used in clinical gait analysis to assess foot deformities and differentiate between static and dynamic conditions for intervention planning. A recent literature review identified 40 segmental foot models, but only a few have undergone validation studies [1,2]. A comparative study found that the Milwaukee Foot Model (MFM) and the Shriners Children's Model (SCM) were the most repeatable and reproducible, particularly in coronal hindfoot alignment due to their use of radiographic or goniometric inputs in local coordinate system construction [3]. However, prior studies focused only on healthy adults. This study aims to compare static alignment and kinematic outputs of the MFM and SCM in pediatric patients with foot deformities.

CLINICAL SIGNIFICANCE

While the MFM and SCM are both anatomically based segmental foot models that have been shown to report similar output, there are differences that need to be understood in both static alignment and kinematics. These differences also become more significant in the presence of deformity.

METHODS

Segmental foot model data were collected from ten pediatric patients referred for clinical gait analysis due to foot deformities. Kinematics for the hindfoot/tibia and forefoot/hindfoot segments were simultaneously recorded using the MFM [4] and SCM [5]. The MFM incorporated x-ray-derived inputs, whereas the SCM was analyzed using (1) marker-based kinematics with goniometer input and (2) marker-based kinematics with radiographic offsets in sagittal, coronal, and transverse hindfoot alignment. Pearson's correlation coefficient (r) was used to assess the relationship between deformity severity and model differences. Paired t-tests ($\alpha=0.05$) compared range of motion (ROM) between models.

RESULTS

Static alignment: Differences in coronal hindfoot severity were observed between the goniometer-based SCM input and the x-ray-based MFM input (Figure 1; mean difference = 6.1°, range = 2-16°). A moderate correlation (r=0.59) was found between deformity severity and measurement differences. Differences in transverse midfoot alignment (Figure 2; mean difference = 14.4°, range = 0-36°) also showed a moderate correlation (r=0.54) between marker-based SCM and x-ray-based MFM measures.

Kinematics: Significant differences in ROM were observed in all three planes of the hindfoot/tibia and in the coronal plane of the forefoot/hindfoot (Table 1). Even when x-ray inputs were included in the SCM, significant differences in hindfoot/tibia motion persisted.

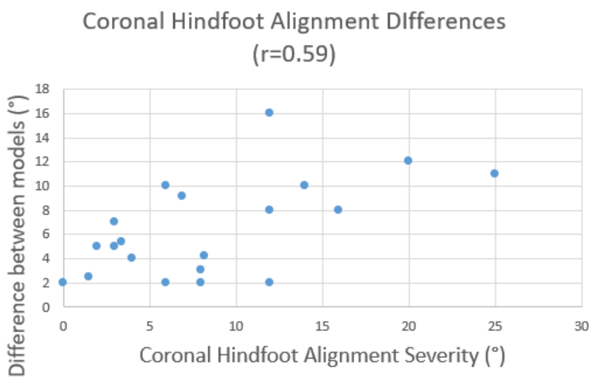

Figure 1: Comparison of coronal hindfoot alignment

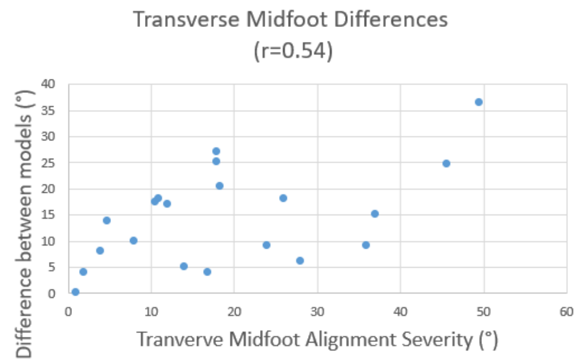

Figure 2: Comparison of transverse plane midfoot alignment

Table 1: Range of motion for Shriners Children's Model, Shriners Children's Model w/ x-ray input, and Milwaukee Foot Model. *indicates statistical significance (α=0.05)

		SCM Average (SD)	**SCM w/ x-ray input** Average (SD)	**MFM Average** (SD)	**Paired t-test (p)** SCM/MFM	**Paired t-test (p)** SCM w/ x-rays/MFM
Hindfoot/ Tibia	Sagittal	17.0 (6.0)	17.0 (5.9)	14.9 (4.6)	<0.001*	<0.001*
	Coronal	9.2 (3.7)	8.9 (3.6)	5.8 (3.4)	<0.002*	<0.002*
	Transverse	9.5 (2.6)	9.4 (3.2)	5.0 (2.6)	<0.001*	<0.001*
Forefoot/ Hindfoot	Sagittal	17.9 (6.3)	17.5 (6.4)	16.6 (6.1)	0.494	0.628
	Coronal	9.2 (2.9)	10.3 (4.1)	12.6 (6.3)	0.007*	0.145
	Transverse	12.0 (5.4)	11.7 (5.3)	11.1 (3.8)	0.39	0.57

DISCUSSION

This analysis presents the differences between two anatomically based segmental foot models. The static alignment results show that as deformity increased, there was more disagreement between the alignment from marker position and goniometer input of the SCM and x-ray input of the MFM. This is consistent with previous findings in adult foot pathology [7]. Dynamic results showed the significant differences in hindfoot/tibia range of motion between the MFM and SCM model both with and without x-ray input. While range of motion differences were less when x-ray input was used, this highlights the potential differences in kinematics beyond only shifts in the curve that can be attributed to differences in factors such as local coordinate system identification and Cardan de-rotation sequences. Use of x-rays can have challenges due to radiation exposure and differences in positioning. However, these results show they should be considered, especially in cases in severe deformity where marker-based segment alignment measures differed more significantly from the underlying skeletal anatomy.

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DISCLOSURES: KMK and RSC are members of the GCMAS Board of Directors.

The Ten-Year Outcome of the Ponseti Method in Children With Idiopathic Clubfoot and Arthrogryposis

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INTRODUCTION

Idiopathic clubfoot (IC) is one of the most common musculoskeletal birth defects in the world. A clubfoot presents with four key characteristics: cavus, forefoot adduction, hindfoot varus, and equinus [1]. IC occurs in isolation; however, clubfoot can occur as part of many genetic syndromes. Arthrogryposis is a condition marked by multiple joint contractures and often, stiff bilateral clubfeet that are notably harder to correct than IC [2]. This study compares outcomes of the Ponseti method in 10-year-old children with IC and clubfoot associated with arthrogryposis and evaluates longitudinal change from ages 5-to-10-years.

CLINICAL SIGNIFICANCE

IC is effectively corrected with a conservative treatment known as the Ponseti method which uses serial casting, a percutaneous Achillies tenotomy, and a prolonged bracing period [1]. Historically, the stiffer clubfoot associated with arthrogryposis has been treated with early invasive surgical intervention but resulted in high relapse of the foot deformity and low long-term success rates [3]. Recently, studies have shown successful short-term correction using Ponseti treatment in the stiffer clubfoot associated with arthrogryposis, but long-term results are unclear [2].

METHODS

This was an IRB approved retrospective review. Ambulatory children with a diagnosis of IC or clubfoot associated with arthrogryposis, aged 8.0-12.9 years who visited our gait analysis lab between 2004 and 2024 were included. All children were treated with the Ponseti method. Children were excluded due to non-idiopathic or non-arthrogryposis-related clubfoot or with a history of posteromedial release. A subsection of the group also visited the lab at age 4.0-6.9 years (2003-2021), and data from those visits were abstracted for longitudinal study. Clubfoot groups were compared with typically developing youth (TDY) by analyses of foot pressure data, passive range of motion (PROM), the Gross Motor Function Measure Dimension-D (GMFM-D), and the Pediatric Outcomes Data Collection Instrument (PODCI). Surgical history was also recorded. For pairwise comparisons, the Shapiro-Wilk test was used to assess normality. Welch two sample t-tests (parametric) and Wilcoxon rank-sum tests (non-parametric) were used to analyze significant differences.

RESULTS

A total of 177 children were included, 48 with arthrogryposis (93 feet) and 129 with IC (190 feet), with an average age of 9.4 ± 0.9 years. Repeat surgical intervention (beyond initial percutaneous Achilles tenotomy) was used in 33% of IC feet and 44% of arthrogrypotic clubfeet. Residual equinovarus and limitations in range of motion were present in both clubfoot groups in comparison to typically developing feet ($p < 0.05$). The foot deformity and PROM restrictions were more severe in children with arthrogryposis ($p < 0.05$). The arthrogryposis group exhibited limited gross motor and global function. ($p < 0.001$) (Table 1). In 5-to-10-year comparisons, both clubfoot groups showed more limitations in ankle motion, but improvements in dynamic equinovarus deformity and function at age 10 ($p < 0.05$).

Table 1. Foot pressure percentages, PROM, GMFM-D scores, PODCI scores for children with IC, children with clubfoot associated with arthrogryposis (A), and typically developing children (TD). Significant results ($p < 0.05$) as per Wilcoxon rank-sum test or Bonferroni correction to Welch two sample t-test are shown with an asterisk.

	Arthrogryposis (A)	Clubfoot (IC)	Typically Developing (TD)	A vs. IC	A vs. TD	IC vs. TD
Foot Pressure						
Heel %	15 (2-34)	32 (21-44)	39 (32-46)	<0.001*	<0.001*	<0.001*
CPPI	-52 (-87-(-11))	-35 (-57-(-9))	5 (-8-24)	0.21	<0.001*	<0.001*
PROM						
Dorsiflexion	-8 (-15-2)	0 (-6-4)	9 (5-15)	<0.001*	<0.001*	<0.001*
Plantarflexion	27 (20-35)	40 (30-50)	63 (57-66)	<0.001*	<0.001*	<0.001*
GMFM-D	31 (26-36)	39 (38-39)	NA	<0.001*	NA	NA
PODCI						
Pain	82 ± 21	85 ± 19	92 ± 14	1	0.0019*	<0.001*
Global Function	73 ± 16	92 ± 9	93 ± 8	<0.001*	<0.001*	0.24

DISCUSSION

Ten-year-old children with IC who underwent Ponseti treatment achieved global functional outcomes indistinguishable from TDY, despite residual foot deformity. Ten-year-old children with arthrogryposis had limitations in function, residual deformity and pain, however, the Ponseti method provides sufficient correction to allow for ambulation with largely conservative management for traditionally difficult-to-correct feet.

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First Ray Mobility Measurement: Reliability and Utility in Healthy and Pathological Feet

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INTRODUCTION

First Ray Mobility (FRM) refers to the superior (inferior) displacement of the first metatarsal under dorsal (planar) directed loads. This metric is associated with plantar loading, pathomechanics, diagnosis, and treatment of numerous foot pathologies. Excessive and limited FRM has been associated with hallux valgus (HV), hallux rigidus (HR), tarsometatarsal osteoarthritis (OA), metatarsalgia, lesser metatarsal stress fractures, plantar fasciitis, planus and cavus foot types, and diabetic foot ulceration [1-8]. Current clinical methods for measuring FRM are subjective, inconsistent, and lack a commercially available tool with inter-rater reliability [2]. To address this, a first ray position and mobility device (MAP1stV2) was developed to provide a reliable and objective measurement of FRM, to improve diagnosis, and treatment planning in pathological feet [2]. The purpose of this study was to determine the reliability of MAP1stV2 for measuring FRM and the utility of this instrument for predicting regions of high plantar stress.

CLINICAL SIGNIFICANCE:

Excessive and limited FRM within the foot has been associated with painful and debilitating foot pathologies including tarsometatarsal OA, HV and HR. Reliably measuring FRM may help clinicians with surgical and non-surgical treatment planning to treat patients with various foot pathologies. Utilization of MAP1st V2 offers a potential solution, providing a reliable method for assessing FRM and improving patient outcomes.

METHODS

This IRB-approved cross-sectional study includes 51 subjects (102 feet), with 29 asymptomatic (15 bilateral planus, 10 bilateral rectus, 1 bilateral cavus, 3 mixed foot types) and 22 pathological (11 Hallux Valgus, 11 Hallux Rigidus) subjects. Structural foot measurements while sitting and standing (Arch Height Index (AHI), FRM, FRP, Arch Height Flexibility (AHF)), and functional foot parameters (peak plantar pressures at the hallux, 1st metatarsophalangeal (MTP) joint, and 2nd MTP joint) at self-selected walking speed while barefoot were collected from each subject. Foot type was determined for each individual using AHI. FRM and FRP was measured using MAP1stV2 , for left and right feet, while sitting and standing. Two raters with experience in biomechanical measures of the foot and ankle were assessed to determine intra and inter-rater reliability of MAP1stV2.The reliability analysis was performed for each foot separately using an ICC(2,1) two-way random analysis with absolute agreement. Multivariate regression models were constructed for predicting medial forefoot pressures. All statistical analysis were performed using SPSS (IBM Ver 28.01).

RESULTS

Amongst cohorts of asymptomatic and pathological feet, MAP1stV2 had a mean intra-rater reliability of 0.85 and a mean inter-rater reliability of 0.70 (Table 1a). Univariate regression showed a negative relationship (p=0.001) between FRM and peak pressure beneath the 1st MTP joint with a goodness of fit of R=0.404 (Figure 1). Multivariate models predicted medial peak pressures by including all of the aforementioned metrics of foot structure, function, and anthropometrics (Table 1b).

DISCUSSION

The 1st metatarsal head loading was negatively related to FRM, suggesting the larger the FRM, the smaller the loading on the plantar 1st MTP joint. Design improvements to MAP1st V2 substantially enhanced the reliability for measuring FRM in both normal and pathological feet. Multivariate regressions models provided increased goodness of fit for predicting medial forefoot stress from measures of foot structure.

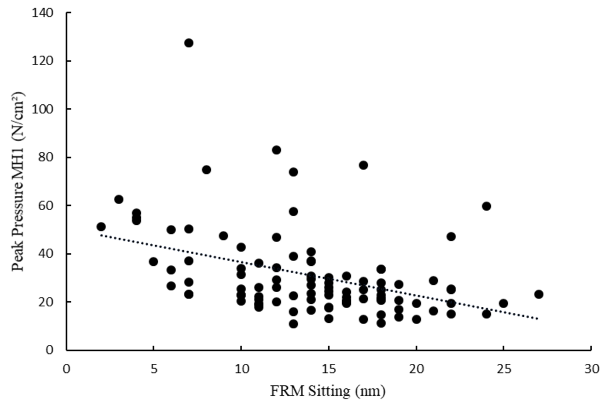

Figure 1: The relationship between FRM loading of the 1st metatarsal head. R=0.404; p=0.001

Table 1a: First Ray Mobility Intra and Inter-Rater Reliability

	Rater 1 Inter-Rater Reliability		Rater 2 Intra-Rater Reliability		Intra-rater Reliability	Inter-rater Reliability
	Test-retest	*Remove-replace*	*Test-retest*	*Remove-replace*	*Rater 1 - Rater 2*	*Rater 1 - Rater 2*
$FRM_{sitting}$	0.91 (0.87-0.94)	0.88 (0.83-0.92)	0.96 (0.94 -0.97)	0.84 (0.78-0.89)	0.90 (0.85-0.93)	0.75 (0.65-0.82)
$FRM_{standing}$	0.77 (0.68-0.84)	0.77 (0.68-0.84)	0.91 (0.85-0.94)	0.83 (0.76-0.89)	0.82 (0.74-0.88)	0.64 (0.50-0.74)
Mean Intra-Rater Reliability ICC(2,1) = 0.85 **Mean Inter-Rater Reliability ICC(2,1) = 0.70**						

Table 1b: Multivariate Regressions for Predicting Medial Forefoot Pressures			
Dependent Variable	Independent Variables	R Value	P Value
PP_{Hallux}(N/cm^2)	$AHI_{sitting}$, $AHI_{standing}$, $FRM_{sitting}$, $FRM_{standing}$, Age, Height, Weight	.465	=.004
PP_{Met1}(N/cm^2)	$AHI_{sitting}$, $AHI_{standing}$, $FRM_{sitting}$, $FRM_{standing}$, Age, Height, Weight	.552	<.001
$PP_{Met1/Met2}$	$AHI_{sitting}$, $AHI_{standing}$, $FRM_{sitting}$, $FRM_{standing}$, Age, Height, Weight	.416	=.035
PP_{Met2}(N/cm^2)	$AHI_{sitting}$, $AHI_{standing}$, $FRM_{sitting}$, $FRM_{standing}$, Age, Height, Weight	.536	<.001

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DISCLOSURE STATEMENT

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The characteristics of foot and ankle movement in school-age children with flexible flatfoot during jumping

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INTRODUCTION

People with flatfoot may have a poorer ability of self-regulation when facing a movement with rapid impact force like vertical jump, which will increase the risk of injuries[1]. Nonetheless, several studies have indicated that adult individuals with flatfoot do not affect vertical jump height, although flat foot have different vertical jump biomechanics [2]. However, research on the performance implications of flatfoot in children remains limited. Epidemiologic investigation found that flatfoot occur most often in children and adolescents, 95% of which are flexible flatfoot(FFF)[3]. In flexible flatfoot, early intervention during childhood and adolescence is the key to prevent injury and dysfunction. The aim of this study was to analyze the biomechanical characteristics of the foot and ankle joints of children with flexible flatfoot compared with children with normal foot during jumping, and to investigate the risk of injuries and the prevention of injuries in children with flexible flatfoot.

CLINICAL SIGNIFICANCE

To investigate the foot and ankle movement characteristics of school-age children with flexible flatfoot during jumping, and to help reduce the risk of sports injuries in children with flatfoot.

METHODS

33 children with flexible flat feet and 39 children with normal feet aged 7-12 years were included in the study. Children with flexible flatfoot were screened according to clinical flatfoot grading [4]and foot posture index[5]. The motion data was collected during jumping by applying the 3D motion analysis. This study has been examined by the ethical review committee of Yueyang Hospital. In this study, a modified conventional gait model[6] and IOR foot model were used[7]. The subject stood barefoot on two force plates, squatted down with hips and knees flexion, and then jumped vertically. After landing, both feet were placed on the two force plates separately. Each subject repeated 3 times. The phase from the maximum knee flexion to the feet leaving the ground is defined as the propulsion phase. A 19-camera (Motion Analysis Corporation, Santa Rosa, CA) motion analysis system combined with 2 force plate (Bertec) was used to collect the motion data and ground reaction force data. The kinematic and kinetic data was analyzed using motion software Visual 3D version 6.01.36 (C-Motion Corporation).

Statistical analysis was performed using the R language. Independent samples t-test and KRUSKAL-Wallis H-test were used to analyses the data.

RESULTS

Compared with the normal group, the jump height was decreased in children in the flexible flatfoot group during jumping propulsion phase($p = 0.01$); navicular drop height and ankle plantar angular velocity were decreased significantly ($p < 0.01$); the Medial Longitudinal Arch angle(MLA) was increased significantly($p < 0.01$). The kinematic and kinetic data shows that the maximum ankle plantarflexion angle and moment were no difference; The maximum dorsiflexion angle of the forefoot and midfoot were significantly increased during the propulsion phase of jumping; the maximum hallux dorsiflexion was significantly decreased ($p < 0.01$); The maximum eversion angle of the forefoot was significantly decreased, and the maximum eversion angle of the midfoot and heel were significantly increased ($p < 0.01$).

Table 1: Jump height, dynamic navicular drop height(DNDH), and ankle motion and kinetic parameters during propulsion (mean(SD)/ M (P25, P75))

Group	Jump height (m)	DNDH (m)	MLA (MAX) (°)	Ankle plantar (MAX) (°)	ankle plantar angular velocity (MAX) (°/s)	Ankle plantar moment (N•m /kg•m)
Normal	0.22(0.20, 0.25)	0.03(0.00)	176.97(6.72)	-39.03(5.46)	-702.61(92.62)	0.85 (0.77, 0.91)
FFF	0.22 (0.17, 0.24)	0.02(0.01)	187.96(7.21)	-37.59(5.50)	-653.11(67.11)	0.81 (0.74, 0.88)
P	0.01*	＜0.01*	＜0.01*	0.12	＜0.01*	0.06

Note: * indicates a significant difference between the flatfoot groups and the normal group.

Table 2: The foot motion during propulsion (mean(SD)/ M (P25, P75))

Group	Forefoot dorsiflexion (MAX) (°)	Forefoot eversion (MAX) (°)	Midfoot dorsiflexion (MAX) (°)	Midfoot eversion (MAX) (°)	Hindfoot eversion (MAX) (°)	Hallux dorsiflexion (MAX) (°)
Normal	-13.62 (-20.11, -9.36)	-4.58 (-7.78, -1.11)	58.57 (53.47, 63.27)	-1.80(5.23)	7.80(6.12)	30.95 (26.41, 38.18)
FFF	-7.12 (-12.19, -2.23)	-5.75 (-9.42, -2.44)	63.65 (59.74, 66.78)	3.74(5.60)	11.61(5.66)	26.86 (21.12, 31.64)
P	＜0.01*	＜0.01*	＜0.01*	＜0.01*	＜0.01*	＜0.01*

Note: * indicates a significant difference between the flatfoot groups and the normal group.

DISCUSSION

The jumping height and other jumping abilities in school-age children with flexible flatfoot are significantly lower than those of children with normal foot. In terms of joint movement performance, the differences are mainly manifested in foot movement. During the propulsion phase of jumping, children with flexible flatfoot have reduced dorsiflexion and eversion angles in the forefoot, while the angle of the midfoot increases. The lower height of the medial longitudinal arch of the foot directly affects the movement performance of the midfoot. The impact at the ankle joint is relatively minimal. However, since the intensity of the exercise is relatively low, the impact on other joint functions has not yet appeared.

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DISCLOSURE STATEMENT

The authors declare no conflicts of interest.

Objective Documentation of the Natural Progression of Gait Decline in Charcot-Marie-Tooth Type 1A: A Case Study

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PATIENT HISTORY

Patient is a female with a diagnosis of Charcot-Marie-Tooth disease (CMT) type 1A who was seen for gait analysis at ages 8, 12, and 14 years. She was the product of a full term birth and walked at 13 months of age. Issues at Test 1 (age 8 yr) included tripping, falling and fatigue as well as pain in both feet and lower legs. She wore bilateral shoe inserts for foot comfort and was physically active. She had no orthopedic surgery andwas referred for a gait analysis to document her baseline gait function for her progressive disorder so that any gait decline could be monitored over time. Tests 2 (12 yr) and 3 (14 yr) were part of a research study with the goal of understanding gait changes over time in CMT 1A. Gait data was reviewed for all tests following the clinical standard of care with a physician review.

CLINICAL DATA

A comprehensive gait analysis was completed 3 times at ages: 8, 12, 14 years. Selected clinical exam findings for all three analyses are summarized in Table 1.

Table 1: Selected clinical exam and temporal findings for the 3 tests.

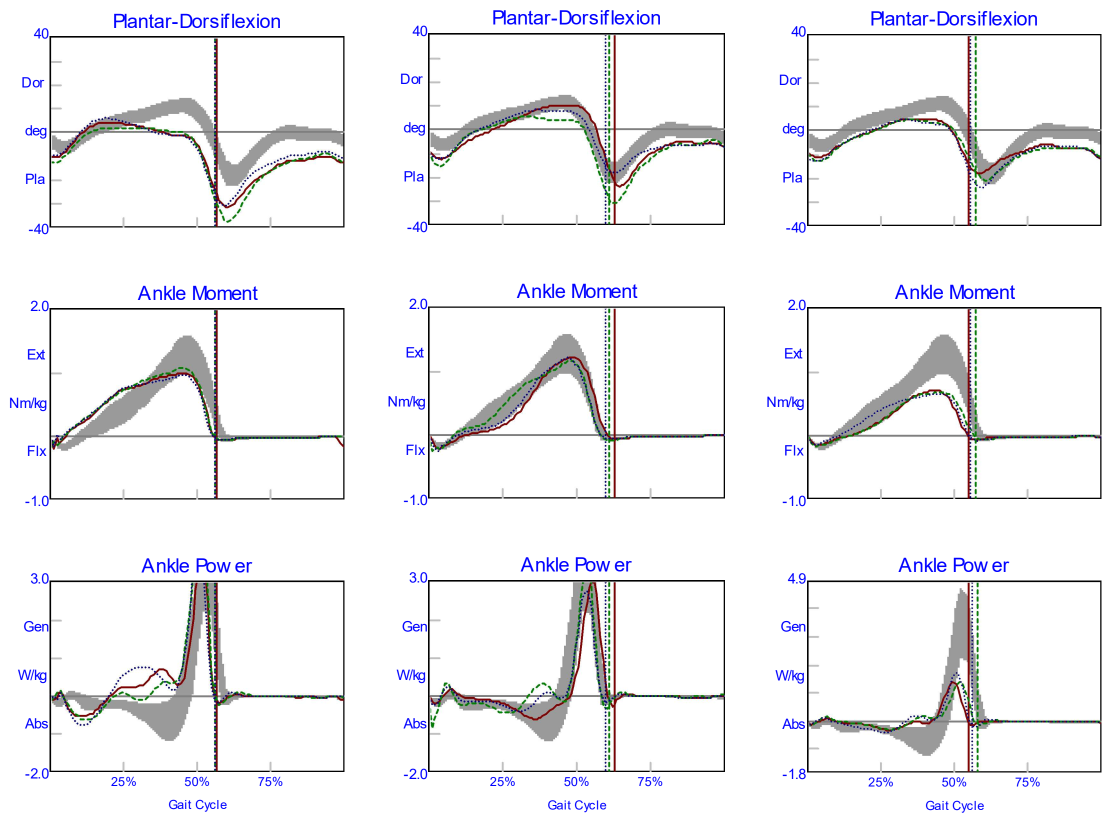
	Test 1	**Test 2**	**Test 3**
Height (cm)/Weight (kg)	125.0/23.4	144.0/31.6	157.0/37.2
Ankle dorsiflexion (deg), knee 0 deg - R/L	5/5	0/0	5/0
Ankle dorsiflexion (deg), knee 90 deg - R/L	10/15	10/10	10/5
Ankle dorsiflexion strength - R/L	5/5	5/5	5/5
Ankle plantar flexion (deg) - R/L	55/55	55/55	55/55
Ankle plantar flexion strength - R/L	5/5	5/5	5/5
Walking Velocity (m/sec)	1.38-1.46	1.13-1.32	1.12-1.17

MOTION DATA

At Test 1, the right ankle kinematics and kinetics showed a premature plantar flexion in mid-stance and increased equinus in swing and initial contact with absence of a dorsiflexor moment in loading response (Fig. 1). Peak plantar flexor moment and power were within normal limits. At Test 2, the kinematic findings normalized and peak kinetics were within normal limits. At Test 3, peak plantar flexor moment and power suggest onset of plantar flexor weakness (not noted in the clinical exam) consistent with a diagnosis of CMT. Left ankle findings were similar for all three tests. Walking velocity reduced over the three tests while stature increased suggesting in decreased gait functionality. The right side ankle gastrocnemius showed reduced electromyography duration and amplitude between Test 2 and Test 3 (data not shown).

TREATMENT DECISIONS AND INDICATIONS

Physician review of Test 1 included the following recommendations: 1) bilateral plantar flexor stretching and night bracing based on the following findings: limited plantar flexor passive ROM, reduced dorsiflexion in stance and initial contact (bilaterally) and 2) no surgery at this time (concerns about lengthening a minimally tight plantar flexor and high risk of progressive weakness related to CMT diagnosis). At Test 2, treatment decision was to continue to watch gait pattern as there were no longer indications for surgical intervention from the ankle kinematic/kinetic data. At Test 3, bilateral AFO's were recommended for the following reasons: reduced peak ankle plantar flexor moment and power. The goal was to provide support especially when fatigued related to the increased functional plantar flexor weakness also manifested with the reduced walking velocity over time.



a) b) c)

Figure 1: Three gait cycles for the right ankle sagittal plane kinematic (first row), moment (second row) and power (third row) for a) Test 1, b) Test 2 and c) Test 3. (Grey band is normal +/- 1 SD)

SUMMARY

The gait analysis data document objectively the trajectory of ankle function decline during gait for a female with CMT 1A. The gait analysis data show decreased function in terms of walking velocity and bilateral ankle kinematics and kinetics. The EMG data show a substantial change in gastrocnemius activity from Test 2 to 3 providing some insight to why this change is occurring that could not be fully appreciated at the time of Test 3 in the clinical exam findings. This case study helps illustrate the benefits of objective documentation of gait function in persons with a progressive disorder. Understanding when initial signs of gait decline begin will assist in determining appropriate treatment as well as timing of the implementation of gene therapy to prevent disease progression.

DISCLOSURE STATEMENT

The authors of this case study have no conflicts of interest to disclose.

UNDERSTANDING PEAK DORSIFLEXION IN TERMINAL STANCE IN YOUTH WITH CHARCOT-MARIE-TOOTH DISEASE

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INTRODUCTION

Charcot-Marie-Tooth (CMT) disease is the most commonly inherited peripheral neuropathy and is often characterized by plantar flexor weakness and/or contracture that result in abnormal gait function [1]. Increased peak ankle dorsiflexion in terminal stance is one of the initial indicators of CMT involvement and is typically associated with increased plantar flexor weakness [2]. However, patients with CMT may also have plantar flexor contracture that can limit dorsiflexion in terminal stance and mask plantarflexor weakness [3]. The goal of this study was to evaluate the relationship between the joint level impairments of plantar flexor weakness and contracture and ankle function during gait in youth with CMT.

CLINICAL SIGNIFICANCE

Understanding how ankle dorsiflexion passive ROM and plantar flexor strength impact ankle function during gait will ultimately help to guide treatment and determine potential risk of lengthening a weak muscle (the gastrocnemius) in a progressive disease. Excessive peak ankle dorsiflexion leads to increased knee flexion in stance and is associated with reduced walking function (slower walking speed), while toe walking leads to instability and forefoot pain.

METHODS

Thirty-six participants with CMT (23 males; mean age 14.1, SD 3.7, range 6-23 years) underwent clinical evaluation, CMT Pediatric Scale (CMTPedS) testing, and gait analysis at one of two CMLA-accredited sites. Clinical evaluation was performed by a pediatric physical therapist and included goniometric measurement of passive ankle dorsiflexion (DF) range-of-motion (ROM) with the subtalar joint held in neutral and the knee flexed at 90° as well as plantarflexion strength assessed through manual muscle testing (MMT). CMTPedS assessment included the lunge test in which maximum dorsiflexion in static weight bearing was measured with an inclinometer placed on the Achilles tendon without controlling the subtalar joint. Thus, two measurements of static dorsiflexion ROM were obtained. Gait analysis was performed walking barefoot at a self-selected speed using the conventional gait model (Plug-in-Gait, Vicon, Oxford, UK). Peak dorsiflexion in terminal stance (TST, 45-65% gait cycle, GC) was averaged for the right limb over multiple strides. Passive DF ROM, weight-bearing DF ROM from the lunge test, and dynamic peak DF during TST were compared using Pearson's correlation.

RESULTS

There was a significant relationship between weight bearing DF ROM from the lunge test and passive dorsiflexion ROM ($r=0.63$, $P<0.0001$; Fig. 1). However, excluding the two participants with the highest passive ROM and the two with the lowest, the relationship was no longer significant ($r=0.14$, $P=0.26$). Peak dorsiflexion during the terminal stance phase of gait was not significantly related to passive ($r=0.21$, $P=0.21$) or weight bearing ($r=0.10$, P=0.56) dorsiflexion ROM. However, for patients lacking antigravity plantarflexor strength (MMT <3), there was a relationship between DF in terminal stance and passive dorsiflexion (r=0.61, P=0.05) while there was no relationship for those with antigravity strength (MMT ≥3) (r=-0.003, P=0.99; Fig. 2).

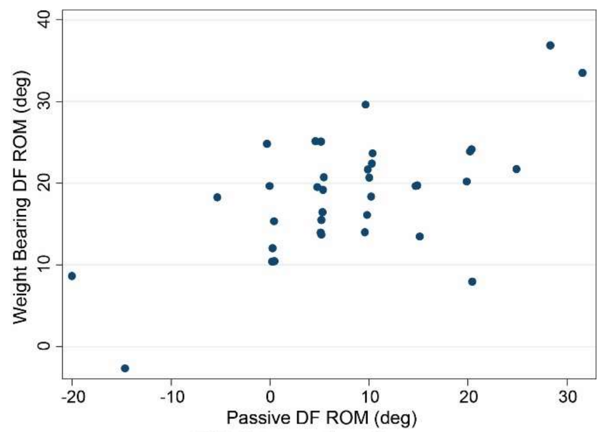

Figure 1: Comparison between passive DF ROM and the lunge test.

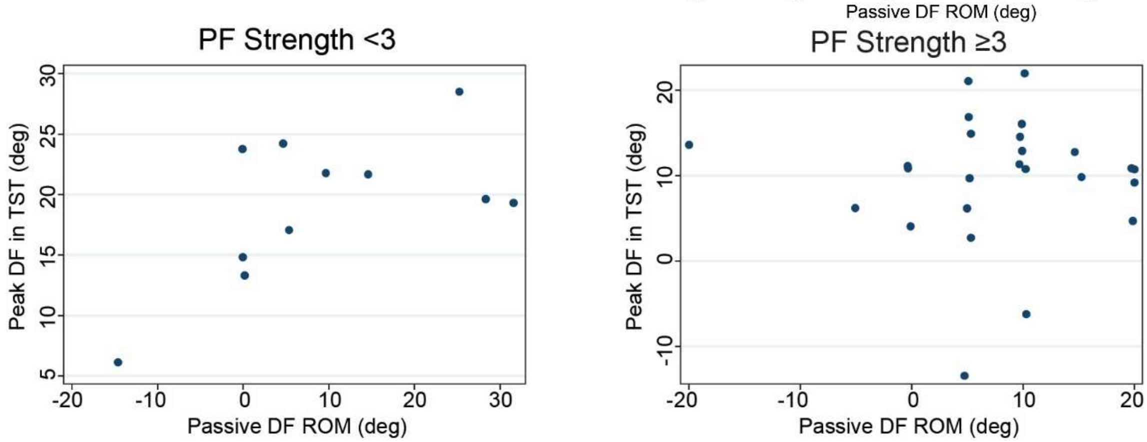

Figure 2: Comparison between DF in TST and passive DF ROM by plantar flexor strength.

DISCUSSION

While passive and static weight bearing dorsiflexion ROM are related, they cannot be used interchangeably. The lunge test measured on average 10° greater dorsiflexion than clinical exam, as expected given the force of body weight and lack of control of the subtalar joint; however, the difference across subjects was variable for typical values of DF ROM (Fig. 1). Regardless of which measure was used, static DF ROM was a poor predictor of peak ankle dorsiflexion during gait in youth with CMT. Only when the plantar flexors had less than antigravity strength did passive DF ROM correlate with peak DF in TST, suggesting that plantar flexor tightness will support ankle function during gait (resist excessive DF in TST) when the plantar flexors are weak. This finding highlights the importance of plantar flexor strength in controlling peak dorsiflexion during gait and suggests that lengthening a less than antigravity plantar flexor may lead to excessive ankle dorsiflexion in TST and other associated gait issues.

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EFFECTS OF ORIENTATION, BLURRED ACUITY AND COGNITIVE TASK ON BALANCE ON A SINGLE AXIS PASSIVELY UNSTABLE SURFACE

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INTRODUCTION

A tilt board is a form of passively unstable surface (PUS), i.e. one that moves in response to motion of a person standing on it [1,2]. In contrast to PUSs with deformable standing surfaces (e.g. thick foam mats), tilt boards have rigid standing surfaces. A PUS like a wobble board also has a rigid stand surface. However, unlike wobble boards, which can rotate about infinite axes, tilt boards are constrained to rotate about a single axis. Consequently, presence of a specific rotation axis enables a user to explicitly dictate how a line between their feet is oriented with respect to the tilt board rotation axis.

Outside of training/exercise domains, there are scenarios where people stand on single axis PUS's both with the rotation axis approximately parallel to a foot-to-foot line, i.e. rotation axis oriented medial/lateral (ML), and with the rotation axis approximately perpendicular to a foot-to-foot line, i.e. rotation axis oriented fore/aft (FA). For examples, skateboarders generally use their skateboards with ML orientation, while persons standing face-forward in a canoe have FA rotation axis orientation. Consequently, it was desired to determine whether rotation axis orientation impacts tilt board balance.

Previous efforts, at this site, involving infinite axes PUS's (e.g. wobble boards, BOSU boards), have demonstrated impacts of blurred acuity and concurrent cognitive tasks on infinite axis PUS balance [2]. Thus, it was also desired to determine whether blurred acuity and cognitive tasks impact tilt board balance, as well as to assess whether any such effects are mitigated by rotation axis orientation.

CLINICAL SIGNIFICANCE

Knowledge, sought by this study, may inform how to differentially manage PUS balance expectations on single axis and infinite axis rigid surface PUSs, and inform regarding impact of impaired visual acuity and concurrent cognitive tasks when standing on such PUSs.

METHODS

Ten participants (9 male, 1 female), with age, height and weight of 25.1±2.6 years, 181.6±9.9 cm, and 766.4±162.9 N, respectively, conveyed informed consent by signing an IRB approved form. Each subject performed tilt board balance task trials with all permutations of two rotation axis conditions (medial/lateral orientations, ML; fore/aft orientation, FA), two visual acuities (clear, CL; blurred, BL), and two concurrent cognitive task conditions (no concurrent task, NCT; verbal fluency task, VFT). For BL trials, blur was imposed by donning eyeglasses with high refractive lens. VFT trials involved reciting words that begin with a specified letter. For all trials, subjects were directed to keep the tilt board as still as able for 45 seconds. Trajectories of reflective markers, placed on the tilt board's rigid standing surface and on subject body segments, were obtained with an optoelectronic tracking system (Qualisys) at 100 Hz. Tilt angle standard deviation (SD_θ) and angular velocity mean for the board surface ($\bar{\omega}_{bd}$) were computed as metrics of balance task performance, i.e. execution of instruction to keep the tilt board as still as able. Angular velocity means were computed for the trunk, pelvis, upper arm and lower arm body segments ($\overline{\omega}_{tr}$, $\overline{\omega}_{pel}$, $\overline{\omega}_{ua}$, $\overline{\omega}_{la}$) to assess balance task strategy.

RESULTS

Axis orientation (AO) and visual acuity (VA) had statistically significant main factor effects on both surface-based balance performance metrics, SD_θ and $\overline{\omega}_{bd}$. SD_θ was significantly greater with ML, while $\overline{\omega}_{bd}$ was greater with FA (Fig 1). Both SD_θ and $\overline{\omega}_{bd}$ were greater with BL (Fig 1). Only the $\overline{\omega}_{bd}$ performance metric demonstrated a significant concurrent task (CT) effect, with greater values exhibited with VFT (Fig 1). All body segment $\overline{\omega}$'s were significantly impacted by all main factors – AO, VA and CT – with all being greater for FA, BL and VFT (Fig 1). Significant AO/VA interactions occurred for all body segment $\overline{\omega}$'s, with BL related increases being substantially greater with FA (Fig 2). An AO/CT interaction approached significance for $\overline{\omega}_{bd}$, (p=0.077), with VFT related increases appearing greater with ML (Fig 2).

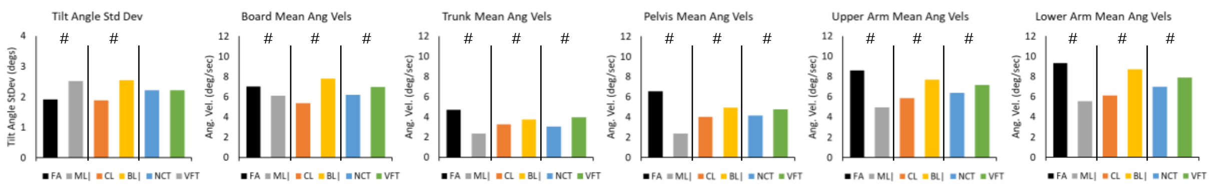

Fig 1. Main effects of Axis Orientation (FA, ML), Visual Acuity (CL, BL) and Concurrent Task (NCT, VFT) on PUS surface-based and body segment-based metrics (# significant main effect, p < 0.05).

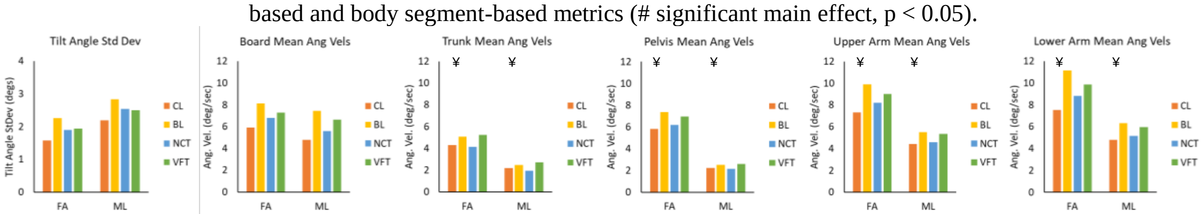

Fig 2. Axis Orientation/Visual Acuity (AO/VA) and Axis Orientation/Concurrent Task (AO/CT) interaction effects on PUS surface-based and body segment-based metrics (¥ significant AO/VA effect, p < 0.05; § significant AO/CT effect, p < 0.05).

DISCUSSION

Differential impact, of AO on SD_θ and $\overline{\omega}_{bd}$, suggests that the movement variability/range aspect of single axis PUS stillness is better controlled with FA, while rate of single axis PUS movement is less effectively managed with FA. Increased rates of upper and core movements ($\overline{\omega}_{tr}$, $\overline{\omega}_{pel}$, $\overline{\omega}_{ua}$, $\overline{\omega}_{la}$) with FA indicates that use of these segments is more integral to balance strategy with FA. Such indication would demonstrate that reliance on lower extremity strategy may be more prevalent with ML. Presence and nature of AO/VA interactions, for all measured body segment $\overline{\omega}$'s, indicates that acuity is more critical for effective use of upper and core segments. The AO/CT interaction approaching significance for $\overline{\omega}_{bd}$ suggests that a concurrent VFT generates greater interference on PUS balance with ML.

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DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

Can Comparing Sibling Data Provide Insights into Progression of Gait Decline in Charcot-Marie-Tooth Type 1A? Clinical Case Study

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PATIENT HISTORY

Patient A (14.3-year-old female) tested in 2024 and Patient B (13.9-year-old male) tested in 2019 are siblings with a diagnosis of Charcot-Marie-Tooth disease (CMT) type 1A. The gait test for Patient A was part of a research study and for Patient B was a baseline test. Patient A walked at 13 months and Patient B at 12 months of age. Both patients reported issues of tripping, falling and fatigue. Neither had previous orthopedic surgery or ankle bracing. Gait data was reviewed for both tests following the clinical standard of care with a physician and treatment recommendations made related to gait function.

CLINICAL DATA

Comparison of selected clinical exam findings for the gait analyses completed at similar ages are summarized in Table 1.

Table 1: Selected clinical exam and temporal findings for Patient A and B at age 14 years.

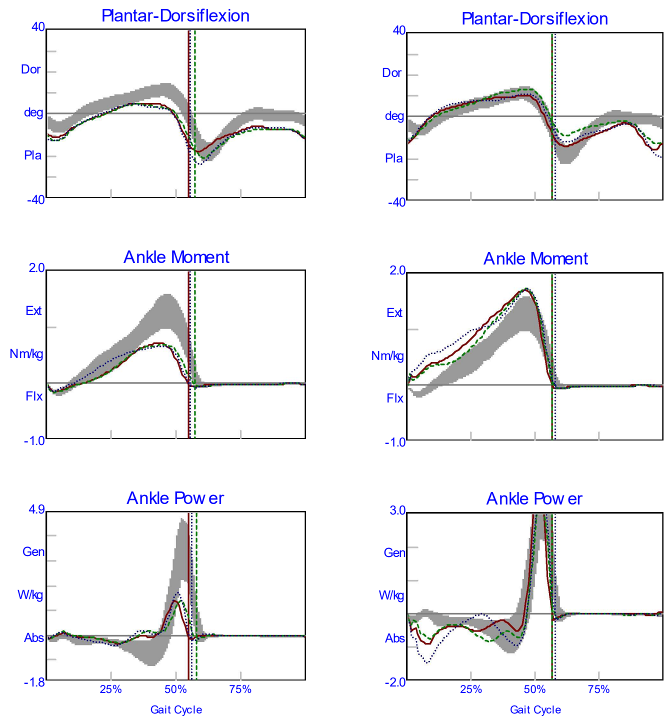
	Patient A	**Patient B**
Height (cm)/Weight (kg)	157.0/37.2	166.5/45.1
Ankle dorsiflexion ROM (deg), knee 0 deg - R/L	5/0	5/5
Ankle dorsiflexion ROM (deg), knee 90 deg - R/L	10/5	15/15
Ankle dorsiflexion strength - R/L	5/5	5/5
Ankle plantar flexion ROM (deg) - R/L	55/55	55/55
Ankle plantar flexion strength - R/L	5/5	5/5
Walking Velocity (m/sec)	1.12-1.17	1.28-1.38
Normalized Walking Velocity (m/sec/height)	0.70-0.75	0.79-0.83

MOTION DATA

At age 14.3, Patient A shows greater evidence of well documented CMT gait findings including a reduction in peak plantar flexor moment and power (Fig. 1) which suggest the onset of a functional plantar flexor weakness (not noted in the clinical exam). At age 13.9, Patient B showed normal peak ankle plantar flexor moment and power (one side only shown). Walking velocity was greater for Patient B than for Patient A, even after normalization to height, as would be expected with normal plantar flexor peak moments and power. The ankle gastrocnemius electromyography (EMG) activity in Patient A was less in duration and amplitude compared to Patient B (Fig. 2).

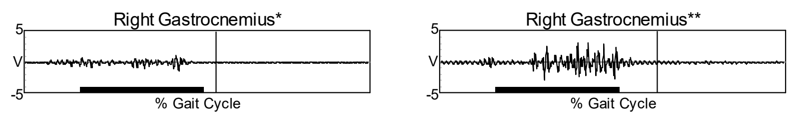
TREATMENT DECISIONS AND INDICATIONS

Physician review of Patient A included recommendation of bilateral ankle-foot orthoses for the following reasons: reduced peak ankle plantar flexor moment and power. The goal was to provide support especially when fatigued related to the increased functional plantar flexor weakness which also manifested with the reduced walking velocity over time. Physician review of Patient B recommended nighttime bracing and plantar flexor stretching to maintain passive ROM. Indications included clinical exam findings of limited passive dorsiflexion ROM, bilaterally.



a) b)

Figure 1: Three gait cycles for the right ankle sagittal plane kinematic (first row), moment (second row) and power (third row) for a) Patient A and b) Patient B. Similar patterns were observed for the left ankle.



a) b)

Figure 2: Comparison of example surface EMG for a) Patient A and b) Patient B.

SUMMARY

The gait analysis data provide an opportunity to objectively compare the gait function between two siblings with the same genetic disease at approximately the same age. This comparison helps illustrate the benefits of gait analysis in persons with a progressive disorder that would not be understood with a clinical exam alone. The gait tests were 5 years apart but followed the same methods. The comparison showed that Patient A had more negative gait findings than Patient B at a similar age. This could suggest that her decline in gait function is progressing more rapidly and may be more severe than her older brother. Understanding that initial signs of gait decline in these siblings do not manifest at the same time suggests that the timing of gene therapy to prevent disease progression may need to be different among siblings and that it may not be appropriate to estimate the timing of treatment for a younger sibling based on their older sibling. Interestingly, subsequent tests for Patient B (at age 17) continue to suggest that his gait findings are not as significant as the younger sister. This may suggest that different treatment dosages are appropriate for siblings as well and emphasizes the importance of individualized assessment and care.

DISCLOSURE STATEMENT

The authors of this case study have no conflicts of interest to disclose.

Automated Gait Classification: Comparison of Automated Algorithms to Expert Classification

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INTRODUCTION

In recent years the significant advances in computer vision and artificial intelligence (AI) are enabling automated detection of joint motions from video; however, current deep learning analysis of video in children with cerebral palsy (CP) has limited predictions to a sub-set of variables that cannot be used for comprehensive clinical decision-making (e.g. walking speed, cadence, and Gait Deviation Index). No widely available automated video-based analysis tool currently exists to quantify and classify sagittal gait deviations in children with CP. Three-dimensional instrumented gait analysis (3D IGA) is considered the gold standard for assessing walking impairments. However, 3D IGA requires a substantial investment in equipment, expertise, and personnel, making it challenging in resource-limited environments. Established classifications, such as those published by Rodda & Graham [1] and Rozumalski & Schwartz [2], have described clinically meaningful gait classifications based on this quantitative data. There is a desire to use video-based gait analysis to assign these gait classifications for use in areas without access to 3D IGA and for remote clinical monitoring. However, an initial attempt to compare gait classifications based on the criteria described by these papers showed significant disagreement between experts in gait analysis. Therefore, the goal of this work was to (1) develop an algorithm to establish quantitative criteria used to assign gait classifications to 3D IGA data automatically and (2) compare the automated classifications to those classified by experts in gait analysis.

CLINICAL SIGNIFICANCE

There is a need for a comprehensive automated tool designed to classify gait deviations in children with CP. Early identification and treatment of abnormal gait patterns through a widely available AI algorithm could substantially improve the function of children with CP. This process will facilitate the "gold standard" classification of a large volume of patients with CP.

METHODS

An automated MATLAB code was developed to automatically assign gait classifications based on criteria established by (1) Rodda & Graham and (2) Rozumalski & Schwartz.

Rodda & Graham: The plantarflexor-knee extension couple index, as described by Sangeux [3], was assigned. For midstance (20-45% of the gait cycle), the average z score for sagittal knee and ankle kinematics was used to calculate this index. This index was then used to define true equinus (knee extension and ankle plantarflexion), jump gait (knee flexion and ankle plantarflexion), apparent equinus (knee flexion and normal ankle), crouch (knee flexion and ankle hyperdorsiflexion), and ankle crouch (normal knee and ankle hyperdorsiflexion).

Rozumalski & Schwartz: The clusters defined by the k-means cluster analysis described in [2] were used to automatically assign levels of crouch severity based on sagittal kinematics of the pelvis, hip, knee, and ankle at midstance (20-45% of the gait cycle). These clusters included

(1) mild crouch with equinus, (2) moderate crouch, (3) moderate crouch with anterior pelvic tilt, (4) moderate crouch with equinus, (5) moderate crouch with anterior pelvic tilt and equinus, and (5) severe crouch.

Following IRB approval, 25 patients who had underwent 3D IGA and were identified with "crouch" were selected for analysis. The automated algorithm was used to assign the two classifications for fifty trials (1 left, 1 right for each patient). Three experts in interpretation of clinical gait analysis (each with over 20 years of experience) classified each trial based on the automated algorithm description. Fleiss's Kappa was used to quantify level of agreement of classification between individual raters and between each rater and the automated classification.

RESULTS

Table 1: Fleiss's kappa comparison of expert inter-rater reliability and each rater.

	Rodda & Graham		**Rozumalski & Schwartz**	
	Fleiss' kappa	**95% Confidence Interval**	**Fleiss' kappa**	**95% Confidence Interval**
Expert Inter-rater Reliability	0.753	[0.644, 0.862]	0.456	[0.377, 0.535]
Rater 1/Automated	0.814	[0.631, 0.997]	0.264	[0.128, 0.400]
Rater 2/Automated	0.868	[0.670, 1.067]	0.460	[0.326, 0.595]
Rater 3/Automated	0.807	[0.619, 0.996]	0.576	[0.434, 0.718]

DISCUSSION

The objective of this work was to develop an automated classification code based on previously established gait classifications for children with CP and compare the automated classification to those of experts in gait analysis. These results showed that even when following an established algorithm, there was disagreement between raters. The Rodda & Graham classification showed "almost perfect agreement" when comparing each rater to the automated algorithm and "substantial agreement" between raters. The Rozumalski & Schwartz classifications showed a higher level of disagreement. Fleiss's kappa showed "fair to moderate agreement" between each rater and the algorithm while there was "moderate agreement" for the inter-rater reliability. This was likely due to more overlap in potential classifications of several of the kinematic graphs. There was also disagreement when some of the trial being analyzed met a given classification but not the entirety of midstance. These examples were taken into account when coding the algorithm but it was difficult for raters to classify based on visual inspection alone, which is likely how a classification would occur in a clinical assessment. While there was some disagreement between raters, the high level of agreement shows promise for this automated algorithm to produced gait classifications representative of clinical exerts. This automated classification serves as an initial model that can be used to facilitate the "gold standard" classification of a large volume of patients with CP for use in validation of AI-based video analyses.

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DISCLOSURES: KMK and RSC are members of the GCMAS Board of Directors.

Relationship Between Pelvic Tilt Measured in Radiographs and Gait Analysis

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INTRODUCTION

Sagittal plane pelvic orientation is an essential parameter for assessing the musculoskeletal health of the trunk and lower extremities. Spine, hip, and lower limb deformities have the potential to alter pelvic orientation and impact overall orthostatic posture. Pelvic tilt is a standard measure of sagittal plane pelvic orientation used to assess gait and develop treatment plans for spine and hip deformities. The literature presents several definitions of pelvic tilt. For this study, we focus on three definitions: spinopelvic tilt (SPT) used by spine surgeons (Figure 1A), anterior pelvic plane tilt (APPT) used by hip surgeons (Figure 1B), and 3D pelvic tilt from (3D PT) gait analysis (Figure 1C)[1-3]. These definitions have no consensus, and there is no published literature on the relationship between the three definitions of pelvic tilt.

Therefore, this study aims to assess the relationship between the spinopelvic tilt, anterior pelvic plane tilt, and pelvic tilt from 3DMA and test if a regression equation can adequately describe the relationship between the different measures.

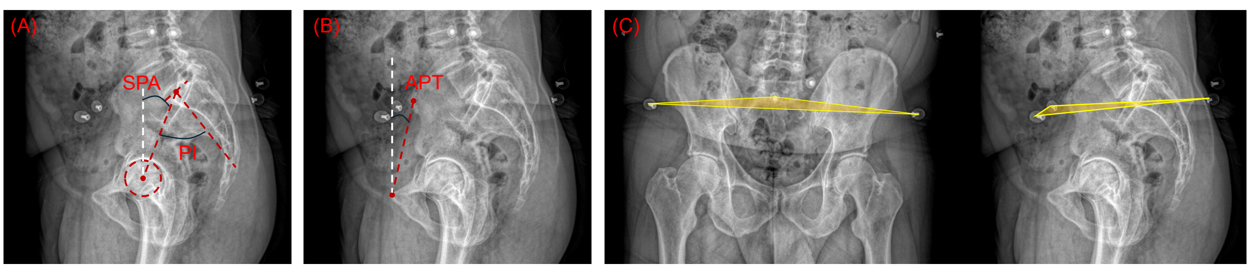

Figure 1. Illustration of (A) spinopelvic tilt (SPT), the angle between line connecting the midpoint of bilateral hip centers to the midpoint of sacral plate and vertical reference line, (B) anterior pelvic plane tilt (APPT), the angle between line connecting the midpoint of bilateral anterior-superior iliac crest (ASIS) to the pubic symphysis and vertical reference line, and (C) pelvic tilt measured using 3D motion capture (3D PT), markers can be seen as white blobs.

CLINICAL SIGNIFICANCE

Developing a regression model would allow spine/ hip surgeons and gait analysis specialists to interpret the three definitions of pelvic tilt. Which, in turn, can help with treatment planning.

METHODS

A consecutive retrospective series of adults enrolled in an IRB-approved study at a tertiary care medical center from 11/2022-10/2024. The participants presented for both 3D motion capture and biplanar radiography (EOS®) on the same day. The EOS visits happened after motion capture with all 3D motion capture markers in place. EOS radiographs of 21 adults (age:38-75years) were reviewed. SPT (including pelvic incidence (PI) and sacral slope (SS)) and APPT were measured directly from the bony landmarks on the EOS. 3D PT was measured using reflective marker landmarks from the same EOS radiographs, i.e., the orientation of a plane constructed using the sacrum and right/ left ASIS markers. An orthopedic surgeon measured SPT, APPT, and 3D PT measurements. A custom MATLAB script was used to visualize the radiographs and mark the various landmarks. Statistical analysis included Pearson's correlation and Holm's method to adjust p-values to account for multiple comparisons.

RESULTS

A linear relationship was found between SPT and 3D PT and between APPT and 3D PT. There was a negative correlation between SPT and 3D PT, $r = -0.64$ ($df=17$; $p = 0.04$), and a positive correlation between APPT and 3D PT, $r = 0.69$ ($df=17$; $p = 0.02$). Figure 2 shows the various associations found in our data. In addition, we also found a strong correlation between PI and SPT/ SS.

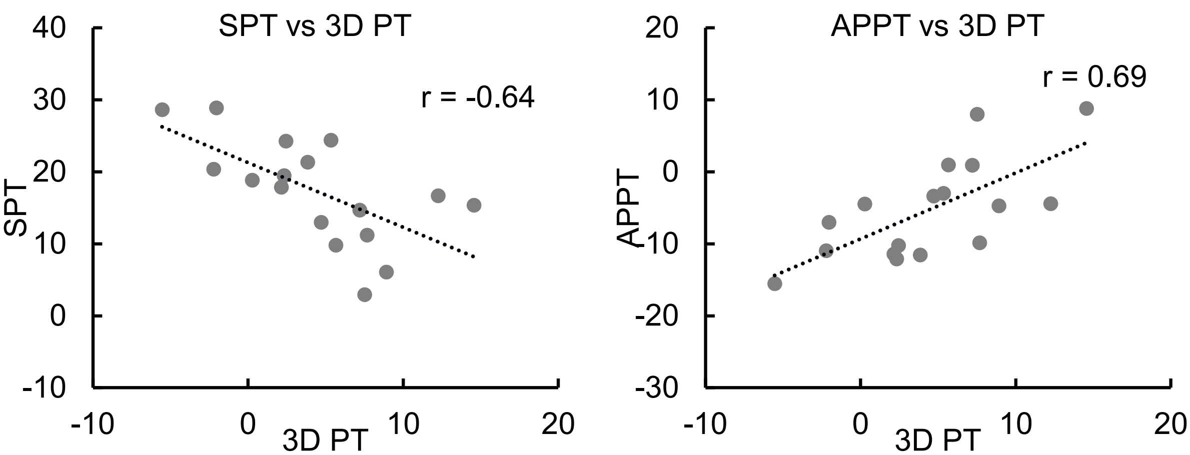

Figure 2. Correlations between (A) SPT and 3D PT, and (B) APPT and 3D PT.

DISCUSSION

Our study provides the initial evidence of the relationship between radiographic and marker-based measurements of pelvic tilt. Our findings support the development of a regression model that would allow spine/ hip surgeons and gait analysis specialists to interpret the three definitions of pelvic tilt.

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DISCLOSURE STATEMENT: There are no conflicts of interest to disclose.

PRE-POST SURGERY OUTCOMES OF A YOUTH WITH SPASTIC DIPLEGIC CEREBRAL PALSY

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PATIENT HISTORY

A 15-year-old male presented with bilateral crouch knee gait and out-toeing with a history of spastic diplegic Cerebral Palsy with superimposed right hemiplegia and a GMFCS 4 ambulatory function. He had a past surgical history of anterior distal femoral hemiepiphyseodesis. The patient used bilateral SAFOs. He required minimum assistance with ambulation with a posterior walker and needed assistance with donning/doffing AFOs and shoes.

CLINICAL DATA

Computed radiography showed bilateral pes planus bilateral coxa valga, and patella alta. The clinical exam revealed a bilateral hip flexion of 100°, hip extension lacking 10° bilaterally, hip abduction of 25° bilaterally, right hip internal rotation of 60° and external rotation of 25°, left knee flexion of 120°, right knee flexion of 130° and lacking 10° of knee extension bilaterally. Decreased hamstring muscle length was measured bilaterally. 30° of left ankle plantarflexion and 20° on the right, 5° of right ankle inversion. Anteversion angles of 30° on the left and 35° on the right internal rotation were measured. Positive Duncan Ely's was present bilaterally, and a positive confusion test was present on the left. There was an increased muscle tone in bilateral adductors, hamstrings, quadriceps, gastrocnemius-soleus, posterior tibialis, and peroneal muscles.

He presented with a level 6 on the FAQ. Lower-than-normal Pediatric Outcomes Data Collection Instrument (PODCI) scores, including in the domains of Upper Extremity and Physical Functioning (33/100), Transfers and Basic Mobility (12/100), Sports and Physical Function (3/100), Pain and Comfort (49/100), Happiness (60/100), and Global functioning (25/100), were noted.

MOTION DATA

The patient underwent pre-operative and 18-month post-operative gait analysis using a modified Helen-Hayes gait model. Pre-operatively, the patient had bilateral hip flexion from mid-swing to terminal stance, increased bilateral knee flexion in stance with delayed peak knee flexion in swing, decreased plantarflexion achieved at the time of toe-off, decreased bilateral ankle dorsiflexion in swing, in the sagittal plane. In the transverse plane, gait deviations included: increased right hemi-pelvis external rotation in swing through midstance, decreased bilateral hip external rotation during swing, increased left knee external rotation in late stance, increased right knee external rotation throughout stance, and increased right external foot progression angles. In the frontal plane, gait deviations included the left side down and right side elevated in late stance and swing, left hip abduction from swing into midstance, and increased right hip adduction throughout the gait cycle.

TREATMENT DECISIONS AND INDICATIONS

Following his gait analysis, the patient underwent SEMLS with bilateral hip adductor releases, bilateral proximal hamstring releases, bilateral removal of hardware of both the distal medial and lateral femurs, bilateral scar plasties of the distal medial and lateral thigh, bilateral rectus femoris recessions, bilateral distal femoral shortening extension osteotomies, bilateral tibial tubercle osteotomies, bilateral patellar tendon advancements, bilateral gastrocnemius recessions, bilateral peroneus brevis intramuscular lengthening, and bilateral triple arthrodesis. Following the surgery, he completed two weeks of inpatient rehab and then completed outpatient physical therapy once weekly. Post-surgery, he had new bracing made, including right SAFO, left KAFO, and right shoe lift of 3 cm. He also was given bilateral night time SAFOs and knee immobilizers.

OUTCOME

18 months post-surgery, he was seen for a follow-up assessment and gait analysis. Postoperatively, left hip abduction improved to 30°, knee extension on the left improved to 15° of hyperextension and 5° of hyperextension on the right, hamstrings improved from in muscle length during hamstring shift tests and SLR, right thigh foot angle improved from 25 to 5° of external rotation and trans malleolar axis improved from 35 to 12° of external rotation. The decreased tone was noted in the right hamstrings and quadriceps.

Kinematics show (**Figure 1**) improvements of the right hemipelvis from external rotation to grossly normal; the right knee achieves extension in stance, and the left knee demonstrates decreased flexion compared to pre-operatively. The range to neutral in bilateral ankles improved but continues to maintain decreased plantarflexion during pre-swing. There were decreased but still above-normal external foot progression angles bilaterally compared to pre-operatively.

Improvements are seen in all domains of PODCI including Upper Extremity and Physical Functioning (Pre: 33, Post: 38), Transfers and Basic Mobility (Pre: 12, Post: 24), Sports and Physical Function (Pre: 3, Post: 11), Pain and Comfort (Pre: 49, Post: 76), Happiness (Pre: 60, Post: 75) and Global Functioning (Pre: 25, Post 37). The post-operative FAQ completed by the father decreased from Level 6 to Level 4. He is now able to ambulate with standby assistance with a posterior walker and completes turns independently with increased time.

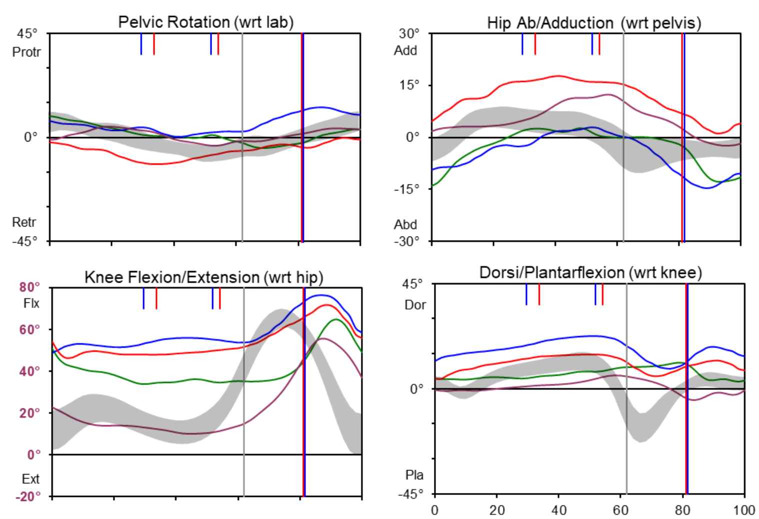

Figure1shows the kinematics for pre- and post-surgical kinematics for pelvis rotation, hid abd/add, knee flex-ext, and dorsi/plantarflexion (Left Pre-Surgery Left Post-Surgery Right Pre-Surgery Right Post-Surgery)

SUMMARY

This case study on a young patient with spastic diplegic cerebral palsy showed that the surgical treatment was efficient in correcting crouch knee gait while restoring function and improving gait. This case study highlights the utility of 3D gait analysis for pre-surgical planning and post-operative outcomes assessment for ambulatory children with spastic diplegic cerebral palsy.

DISCLOSURE STATEMENT

The authors have no conflict of interest to disclose.

Gait Deviations and Compensatory Mechanisms Following Limb Salvage: A Pediatric Case Study

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PATIENT HISTORY

A highly competitive 10 year-old male presented to Sports Medicine clinic with insidious shin pain. Patient and family report pain worse with physical activity and performance decline. The patient received a tall walking boot and restricted activity. Follow-up MRI results revealed consistent finding of a ruptured Brodie's abscess of the right tibia. Biopsy results revealed malignant cell formation, further classified/diagnosed as Ewing's Sarcoma.

Patient was enrolled into AEWS0031 treatment protocol which involves 14 cycles of chemotherapy with alternating vincristine-doxorubicin-cyclophosphamide (VDC) and ifosfamide-etoposide (IE) cycles, with a primary tumor resection.[1] After 11 cycles of neoadjuvant chemotherapy prior to radical resection of the right tibia and intercalary allograft reconstruction using the ipsilateral vascularized fibula by the orthopedic oncology and plastic surgery team. Post-operatively, patient experienced full thickness necrosis with exposed bone and hardware of the surgical site. Plastic surgery performed a soft tissue reconstruction using muscle tissue of the medial gastrocnemius flap and skin grafting. Following surgical resection, reconstruction, and surgical wound debridement, the patient was cleared to complete the remaining 3 cycles of chemotherapy. At 9 months status post-radical resection of Ewing's Sarcoma in his right tibia, the patient was able to return to running.

CLINICAL DATA

Patient was seen in the gait lab at 15months post tibial resection. On physical exam, the patient had full strength (5/5) bilaterally at the hips, knee, and ankles. He had knee hyperextension on the right (R) and decreased dorsiflexion (DF) range of motion (ROM) on the R. The patient had symmetrical leg lengths on physical exam.

Table 1: Clinical Exam Findings

	ROM		**Strength**	
	L	**R**	**L**	**R**
Hip Flexion	120	120	5	5
Hip Extension	0	0	5	5
Knee Flexion	150	150	5	5
Knee Extension	0	15	5	5
Single Anterior Popliteal	40	35		
Dorsiflexion (knee 0°)	10	5		
Dorisflexion (knee 90°)	20	5	5	5
Plantarflexion	40	40	5	5

MOTION DATA

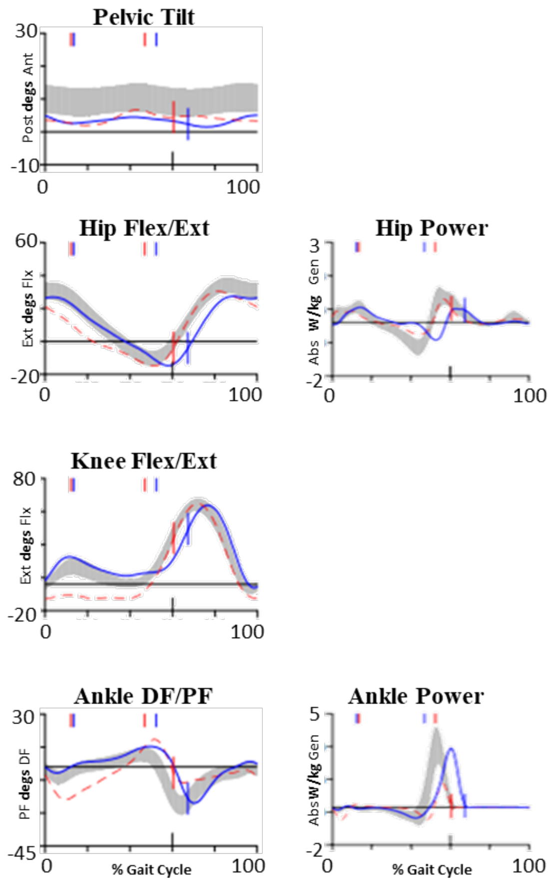
Gait data was collected shod using a 15-camera motion analysis system at 120Hz, and a representative trial was chosen for analysis. Temporospatial parameters indicated he had slightly longer stance phase on the left (66% of gait cycle) compared to the right (60%). He also had a decreased cadence (100 steps/min; 83% age-matched peers) and decreased speed (0.99 m/s; 85%)

On the right side, he demonstrated posterior pelvic tilt, possibly due to tight hamstrings, increased hip extension during early and midstance with a lack of loading response at the knee, which was in frank hyperextension, and increased plantarflexion (PF). The decreased R KF during stance contributed to a lack of KE moment and decreased knee power on the R side. He also showed decreased plantarflexion (PF) at push-off on the R side, even with full strength at the ankle, leading to decreased R ankle power generation. He did have slightly increased hip power generation at toe-off to compensate for the decreased power at the ankle.

He had a slightly asymmetric pelvic obliquity with the right side down, despite equal leg lengths on clinical exam. He had slightly increased pelvic rotation ROM throughout stance. The right knee was noted to have increased knee valgus. The patient demonstrated R external hip rotation and foot progression during mid-swing, likely to help clear his foot due to his lack of PF power generation.

Overall GPS scores were good with the R (7.2 ± 0.6) slightly greater than the L (6.4 ± 0.7), with primary deviations noted for R hip flexion (7.5 ± 0.7), knee flexion (12.0 ± 0.4), and ankle dorsiflexion (9.7 ± 0.4).

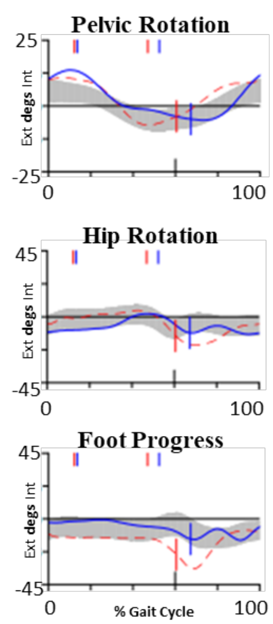
Fig 1. Sagittal gait kinematics/kinetics



SUMMARY

This case involved a 10-year-old athlete with previous right tibia resection for Ewing's Sarcoma. Motion analysis provided understanding of the functional implications of the limb salvage procedure used in conjunction with chemotherapy, which allowed the oncology team to avoid amputation. The patient has now returned to full activity, including competitive running, with minimal gait deviations, including reduced ankle plantarflexion and power generation at toe-off. Future analysis of his running mechanics may provide additional insight into his functional recovery following limb salvage.

Fig 2. Transverse gait kinematics



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DISCLOSURE STATEMENT

KTF is a 2025 GCMAS Conference Co-Chair.

Variation in Activity Level Measurement Using Wrist- and Ankle-Based Activity Monitors: Preliminary Findings from a Pilot Cohort

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INTRODUCTION

Single event orthopedic multi-level surgery (SEMLS) is standard of care to surgically address lower extremity impairments in children with cerebral palsy (CP). Following SEMLS, children experience a decrease in function requiring extensive physical therapy (PT) to regain function. Recovery patterns vary, but changes during recovery from SEMLS are not well described and measures to track across recovery are not agreed upon.

Wearable activity monitors have grown in popularity over the past decade and present an opportunity to assess patient mobility unobtrusively in a real-world setting. For measures of step count, ankle-based methods such as those afforded by the Stepwatch activity monitor (Modus Health LLC; Edmonds, WA) have demonstrated high accuracy and precision [1]. Conversely, wrist-based methods such as those provided by the Actigraph activity monitor (Actigraph; Pensacola, FL) have demonstrated value in measuring sleep quantity and quality [2]. In a cohort wearing both types of monitor, the question arose as to whether one monitor could appropriately describe both daily activity (step count) and sleep.

CLINICAL SIGNIFICANCE

Field monitoring of real-world activity levels following orthopaedic surgery plays an important role in understanding therapeutic progress, functional gains, and program adherence. Understanding the variations associated with different measurement technologies is critical to accurate and precise assessment. Comprehensive assessment may require the use of multiple devices to quantify all aspects of activity and inactivity; however, using the fewest and least obtrusive devices may lead to better patient adherence.

METHODS

This report is part of a larger study to determine the feasibility of data collection methods to track recovery in children with CP during the first 3 months after SEMLS. Measures of interest include motor function, real world physical activity, sleep, patient reported outcomes and PT dose. This report will focus on physical activity measures in a subset of patients.

Overall study eligibility required a diagnosis of CP and an orthopaedic care plan involving SEMLS. At two different time points (*Pre*, prior to surgery; *Post*, ~3 months following surgery), each child was provided with an Actigraph activity monitor to capture sleep information, and a Stepwatch activity monitor to collect step count information. All devices were calibrated in-clinic according to manufacturer specifications. Participants were instructed to wear each activity tracker for the entirety of the measurement period, including overnight. Activity and sleep measures were collected over a 7-day period.

At the conclusion of each measurement period, the activity trackers were returned to the lab for data extraction. Daily step counts were compared between the Stepwatch and Actigraph devices, as well as time spent in each of three activity levels (Low, Moderate/Medium, High/Vigorous). The small cohort size limited the ability to complete a full statistical analysis. For purposes of this report, data are compared between devices on a per subject/per day basis.

RESULTS

Exemplar step count data (Figure 1a) demonstrates the tendency of the Actigraph device to overestimate the number of steps taken by the subject. Across subjects, overestimates ranged from 7% to 225%. These findings agree with prior reports [3].

Similar differences were seen in rating of activity intensity, with the Actigraph reporting relatively higher portions of time spent in both Low (Figure 1b) and Moderate activity levels. Differences in Low level measurement ranged from 12-28%. Differences in Moderate level measurement ranged from 2-10%.

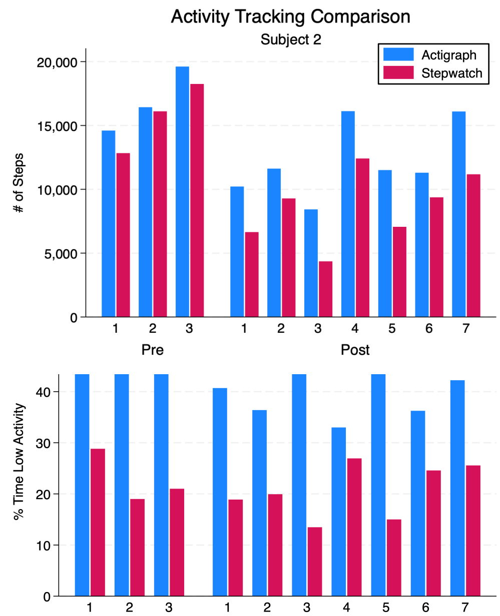

Figure 1a) Exemplar step count and 1b) Low activity level duration (Subject 2).

DISCUSSION

The measurement of activity levels following orthopaedic intervention is important, but the means of making those measurements warrant equal attention. While the validity of ankle-worn devices has been well-established, wrist-worn devices have gained in popularity and market share due in part to convenience and familiarity. Results from the small group assessed in this study demonstrate that in general, Actigraph-based measures overestimate mobility activity compared to Stepwatch-based measures. This overestimation is seen in both overall step counts and in the assessment of activity intensity levels. The variation in discrepancy between subjects suggests that these differences are not due to a simple discrepancy in hardware parameters (i.e. cut thresholds for low, moderate, and high activity). Subject-specific scaling may be an appropriate way to address these discrepancies; further study is warranted in a larger cohort to better understand these relationships.

ACKNOWLEDGMENTS

This study was supported in part by the Division of Patient Services Research Services at Cincinnati Children's Hospital.

DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

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Utility of gait analysis in treatment of pseudoachondroplasia: a case study

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PATIENT HISTORY:

The patient is a 10-year-old female with history of pseudoachondroplasia. She had undergone previous surgical intervention of hemi epiphysiodesis at bilateral knees and ankles for prevention and correction of deformities along with a tibia and fibula valgus rotation osteotomy. Despite these interventions she continued to have significant anomalies of her lower extremity causing pain and decreased ability to walk. She was referred for a three-dimensional(3-D) gait analysis in preparation for surgical correction.

CLINCAL DATA:

Significant clinical exam data was left (L) knee genu varum of 12°, right (R) knee genu valgum of 6° and knee extensor strength of L 5/5 and R 4/5 with pain. Other data on clinical exam was not remarkable. Patient was noted to have ankle varum bilaterally (Figure 1).

Figure 1: Clinical pictures

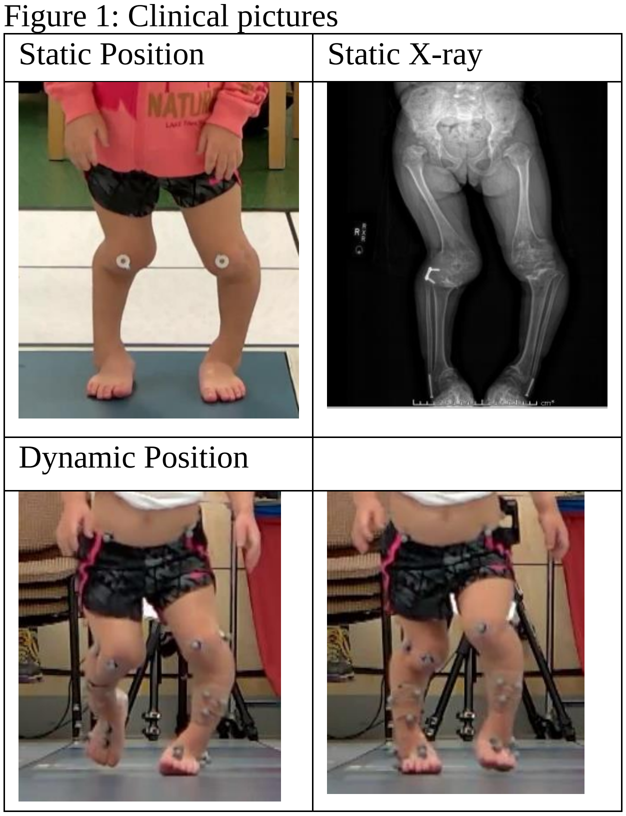
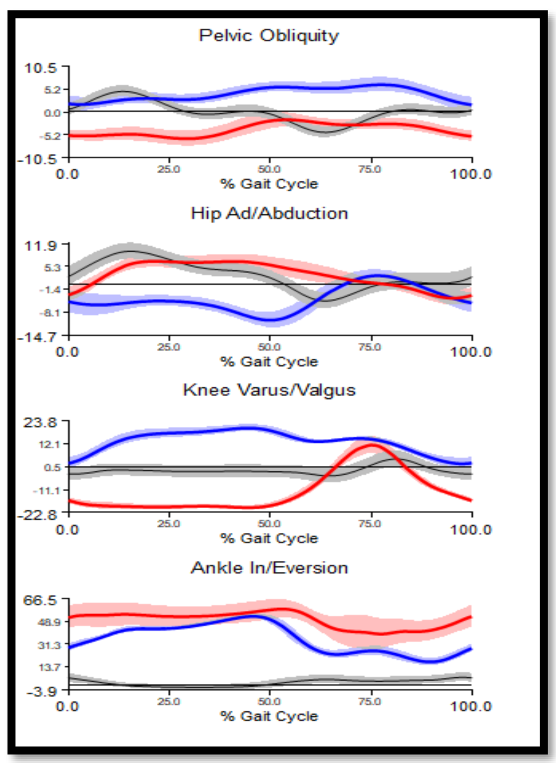


Figure 2: Frontal Plane Kinematics
Red=Right, Blue=Left, Gray=Norms



MOTION DATA

3-D kinematic data were obtained utilizing a 6 degree of freedom model (Vicon, Inc., Oxford, UK). Stride characteristics were significant for decreased stance time on the L of 78% of normal (% N) with R stance time of 86.5%N with double limb support 173.8% N. Step length was equal on both sides. Self-selected walking speed was 77.4% N. Gait deviation index (GDI) was L 73.8 and R 84.0. Kinematics were significant in the frontal plane for L knee varus peak of 22 degrees and R knee valgus peak of 23 degrees, pelvic obliquity with L side elevated, L hip abduction of 6 degrees in stance and ankle inversion bilaterally with peak of near 65 degrees. (Figure 2)

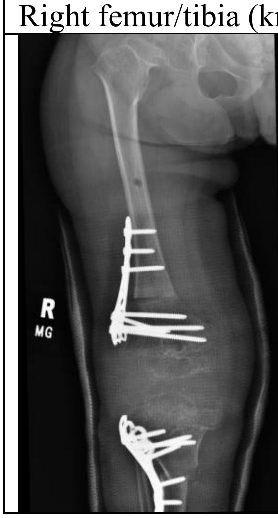
TREATMENT DECISIONS AND INDICATIONS

Pseudoachondroplasia is a rare inherited disorder that affects bone growth, affecting 1 in 30,000 people. Windswept limb deformity is a common disorder of people with pseudoachondroplasia as seen in our patient. Patients undergo significant orthopedic intervention when faced with this disorder. Undergoing 3-D gait analysis allowed our surgeon to assess and treat our patient's limbs more accurately. The patient underwent complex staged surgical correction of her right knee and ankle utilizing temporary in surgery external fixation and osteotomies at both the femur and tibia. The surgeons successfully corrected the mechanical axis of the knee. However, the patient's ankle varus was so severe that weight bearing would be difficult. Consequently, a second surgery was performed two weeks later to correct the ankle varus, enabling weight-bearing on the right extremity. (Figure 3) The surgeons learned the importance of ensuring all necessary corrections are made by thoroughly reviewing all data points.

SUMMARY

The patient had improved static alignment immediately post operatively (Figure 3). The surgeons were happy with the alignment they were able to achieve and felt more prepared for the surgeries after the gait study.

Figure 3 Post operative x-rays

Right femur/tibia (knee joint) post op	Right Tibia (ankle) post op
	

DISCLOSURE STATEMENT

None of the authors have any conflicts of interest to declare

Which Activity to Use to Identify Optimal Knee Axis for Sport Movements: Walks or Squats?

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INTRODUCTION

The Motion Lab (TML) at Sunny Hill Health Centre in BC Children's Hospital uses marker-based motion analysis for clinical gait analysis and sports motion analysis post-ACL reconstruction (ACLr). Since the functional knee axis is difficult to identify with medial and lateral knee markers, "crosstalk" between the sagittal and coronal planes of knee joint motion can be observed when the coronal knee kinematics appear to be similar to sagittal knee kinematics during gait.

Cross-talk between planes can be reduced by optimizing the functional knee axis in the patient's biomechanical model, such as: i) physically readjusting the medial and lateral knee marker placements after reviewing kinematic data and iteratively reaching a subjective appropriate characterization of the knee, ii) using a knee axis device (KAD) [1], and iii) a post-hoc knee axis correction algorithm (KAC) that virtually "corrects" the knee marker positions based on an optimization criteria. TML uses a KAC modified from Baker et al. [2] to identify the optimal knee marker placement for reduced knee coronal range of motion (RoM) for gait kinematics. The TML KAC is only used on patients who achieve a minimum of 30 degrees of sagittal knee RoM in gait [2]. The TML KAC uses knee kinematic data as an input, and outputs the changes in the thigh offset angle (i.e. axial rotation of the thigh coordinate system) that results in a minimized knee coronal angle RoM over the gait cycle.

In TML's sports motion analysis, patients perform gait trials and sports movement tests that exhibit an increased knee RoM compared to gait. The perceived need for knee axis correction still exists for sports motion analysis, but due to the nature of the increased knee RoM, utilizing gait trial data as inputs for the TML KAC may not be appropriate, as the optimal functional knee axis may not be identified. In this study, we compared hip and knee kinematic outcomes when using squat trials vs gait trials, as inputs to the TML KAC.

CLINICAL SIGNIFICANCE

Knee axis optimization methods are often used to address the challenge in identifying the functional knee axis. The data that informs these methods should intuitively be representative of the movements that the optimization will be applied to. These findings can influence clinical and research protocols for capturing knee kinematics for any movements.

METHODS

For this non-randomized, cross-sectional study, all participants coming to TML for their sports motion analysis appointment were included. TML physiotherapists applied 43 retro-reflective markers according to the PRiSM sports protocol marker set [3]. TML uses a 12-camera marker-based Qualisys motion capture system. After a static calibration trial, participants performed three consecutive squats and five walking trials. Participants then completed the drop jump, single leg hop, and 45 degree cut activities as per the PRiSM Sports

Protocol [3]. Gait trials were used as inputs to the TML KAC, with outputs implemented to modify the knee and hip kinematics of the sports movement tests. Then, the squat trials were used as inputs to the TML KAC to obtain a second set of modified hip and knee kinematics. The thigh offset angles in the transverse plane were recorded for each correction, and the hip and knee kinematics were plotted for the first landing of the drop jump. Descriptive statistics were generated for the differences in thigh offset angles between the gait and squat KAC.

RESULTS

Patients (n=5; 4 female; 4 right ACLr) were a mean of 17.9 (range: 17.1-18.4) years old. Each side/leg was accounted for separately (total of 10 legs analyzed). Across patients, the average sagittal knee RoM was 67.3 (sd = 4.1) degrees for gait trials and 100.1 (sd = 17.6) degrees for squat trials. The mean difference between the gait and squat KAC in the thigh offset angle was 8.0 (sd = 2.5) degrees of external thigh rotation, with the squat KAC more externally rotated for the drop jump (Fig. 1). For the coronal knee RoM, the mean difference between gait and squat KAC was 4.3 (sd = 1.4) degrees, suggesting a reduced RoM with the squat KAC.

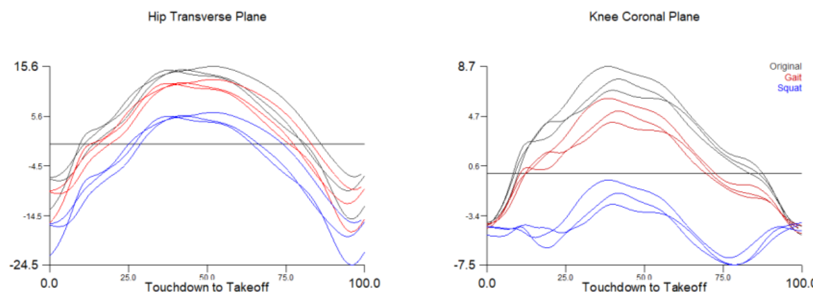

Figure 1 - Sample transverse hip (left) and coronal knee (right) RoM for the initial landing of the drop jump. The original data, prior to running TML KAC (black), corrected data using the gait trials (red) and using the squat trials (blue) are shown.

DISCUSSION

The movement used as input for KAC influences the resulting correction of the transverse hip and coronal knee kinematics. The differences in the correction may affect the clinical interpretation and recommendation for patients post-ACLr. While different knee axis optimization methods exist, all utilize an 'input dataset' to help guide the correction of the knee axis. We intend to collect and present a larger patient sample to identify possible statistically significant differences. Practitioners utilizing knee axis optimization techniques should be cognizant of the effects of different activities used to correct knee axes in movement trials.

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DISCLOSURES

The authors have nothing to disclose.

A comparison of Plug in Gait and CGM2 1.0

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INTRODUCTION

The Plug in Gait (PiG) model, developed by Oxford Metrics (VICON), is a commonly used biomechanical model for 3-dimensional gait analysis in clinical settings. While it is user-friendly and has undergone validation (Kabada et al., 1990), several well-documented limitations remain unaddressed. These limitations include: the accuracy of the location of the hip joint center (Sangeux et al., 2014); a simplistic model of the foot; difficulty in identifying anterior superior iliac crest marker landmarks in people with significant abdominal adipose tissue; and difficulty in accurately defining the coronal place of the femur.

To overcome these challenges, a new model, called pyCGM2, has been introduced, evolving through six iterative versions (https://pycgm2.netlify.app/). This updated model seeks to enhance the existing PiG model by leveraging technological improvements. Furthermore, pyCGM2 is coded in Python, an open-source programming language, making it freely accessible to all users. The open nature of the code enables full transparency, allowing users to examine and understand the underlying calculations.

The first model of pyCGM2 (model 1.0) is designed to closely mimic the PiG model. Initial studies have shown this model can produce kinematic and kinetic outputs similar to those of the PiG model (Leboeuf et al., 2019; Horsak et al., 2021). However, these evaluations have been conducted on datasets involving healthy individuals, with no analysis performed on clinical populations. Furthermore, there have been updates to the model as issues have arisen and the current version is yet to be proven. Consequently, the objective of this study was to compare kinematic data generated by the PiG model and the pyCGM2 1.0 model using a clinical dataset.

CLINICAL SIGNIFICANCE

The pyCGM2 model offers some improvements to the traditional clinical gait model. Before the pyCGM2 model can be clinically implemented, it must be fully tested to understand how it performs on a clinical dataset.

METHODS

This prospective study included 10 patients who attended a clinical gait analysis service (52 ± 12.27 years, 40% female). Of these, five participants were stroke survivors, two were diagnosed with cerebral palsy diplegia, and one with hereditary spastic paresis, one with multiple sclerosis, and one was an orthopaedic surgical case. This study was approved by Monash Health Human Research Ethics Committee (No. 15512L). All participants received written and oral information about the study and were informed of their right to decline/withdraw and that doing so would not impact their care. All individuals provided written consent to participate in this study. Fourteen retroreflective markers were positioned according to the Plug-in-Gait model (VICON, Oxford, UK). Participants were asked to walk barefoot along a 10-meter walkway at their self-selected walking speed until 5 clean force plate contacts were achieved per side. A total of 20 trials were analysed, comprising 20 left strides and 20 right strides in total. The kinematics calculated using the PiG model were compared with those generated by the pyCGM2 (Version 4.2) 1.0 model, both using the models embedded within Nexus (Vicon, Nexus 2.16). To assess the differences between the two models, root mean squared differences (RMSD) were calculated for each point throughout the gait cycle of both legs (Leboeuf et al., 2019).

RESULTS

The RMSD values ranged from 0.08-13.59 degrees. The coronal plane has the lowest average difference between models (0.65 degrees), with the transverse having the largest (4.73 degrees) (Figure 1). Knee rotation and ankle plantar/dorsi flexion had the largest differences (Table 1).

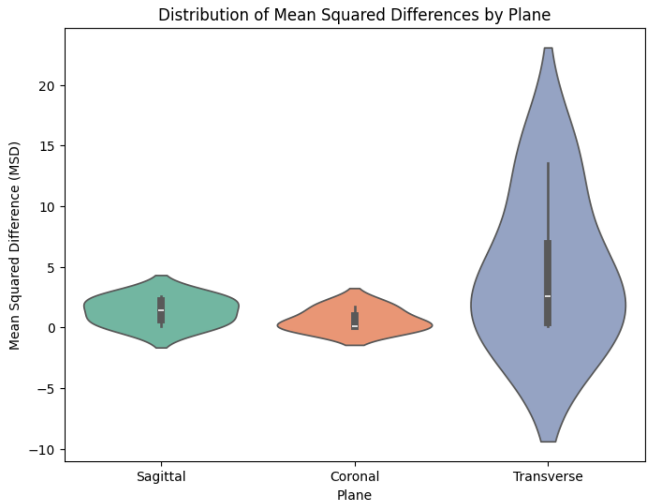

Figure 1. Violin plot showing RMDS-values pooled across all joints

Table 1: RMSD values (degrees) of each kinematic output

Sagittal	RMDS	Coronal	RMDS	Transverse	RMDS
Pelvic tilt	0.09	Pelvic obliquity	0.08	Pelvic rotation	0.11
Hip flex/ext	0.80	Hip abd/add	0.14	Hip rotation	4.71
Knee flex/ext	2.06	Knee var/valg	1.74	Knee rotation	13.59
Ankle dorsi/plan	2.59			Foot progression	0.52

DISCUSSION

This study compared the PiG model with the pyCGM2 1.0 model to determine if it was a direct clone of the PiG model. There are some large differences that exist in the transverse and sagittal planes. Caution is therefore suggested when considering the appropriateness of this model for clinical implementation until further work is done to understand the causes of these differences.

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DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

Ability of Children with Persistent Idiopathic Toe Walking and a Moderate Calf Contracture to Achieve a First Rocker in Gait

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INTRODUCTION

Toe walking is a common developmental pattern that usually resolves as a child grows. When all other causes of toe walking are excluded, children with persistent toe walking are often diagnosed with idiopathic toe walking. One method to help differentiate a child with a neurologic cause is to evaluate if the child can alter their typical gait pattern of toe walking to a heel contact pattern. Many children with moderate contractures appear on visual exam to be able to normalize their gait. Westberry et al. reported that 40% of limbs without a first rocker in self-selected walking achieved a first rocker in best-walk with this group having a wide range of dorsiflexion with knee extended on physical exam [1].

CLINICAL SIGNIFICANCE

This purpose of this study was to determine the percentage of children with persistent idiopathic toe walking (ITWp) and moderate equinus contractures who can achieve a first rocker in a best-walk pattern compared to their self-selected walking.

METHODS

This prospective multi-site study recruited children with ITWp, age 6-18 years, and dorsiflexion with knee extended from 10° plantarflexion to 5° dorsiflexion. Lower extremity kinematics were collected for self-selected and best-walk trials. Criteria to achieve a first rocker were defined as an initial contact ankle angle of >5° plantarflexion with any downward movement toward plantarflexion within the first 12% of the gait cycle [2].

RESULTS

Sixty-five children participated in this study. A first rocker was present for 8% of the limbs in the self-selected condition. For the best-walk condition, 50% of the limbs had a first rocker which was a significant increase ($p<0.001$). The mean (SD) ankle dorsiflexion with the knee extended on physical exam for those limbs with a first rocker was -3° (5) (plantarflexion) significantly different from those limbs that did not achieve a first rocker that was -7° (4) ($p<0.001$). During gait, there was a significant increase in dorsiflexion at initial contact and maximum dorsiflexion in stance with best-walk ($p<0.001$) but no difference in knee flexion at initial contact between the conditions ($p=0.7$), Figure 1.

DISCUSSION

Despite having a moderate equinus contracture, this group of children with ITWp could volitionally alter their gait pattern from self-selected to best-walk via overall increased dorsiflexion, resulting in 42% more limbs achieving a first rocker in the best-walk condition.

Westberry et al. found similar results in a group of children with ITW and a wider range of equinus contracture [1]. The ability to achieve a first rocker on demand suggests a less severe gait impairment and might be a measure to guide clinical decision making (e.g. no treatment or less aggressive treatment for children with ITWp who can achieve a first rocker on demand). Further research, including outcomes assessment, will be required to validate this approach. Using IGA to evaluate for a first rocker may help guide treatment as children as achieving a first rocker has been used as an outcome measure [2]. Future research may help delineate which children would best be treated with more aggressive treatments, such as serial casting or surgery.

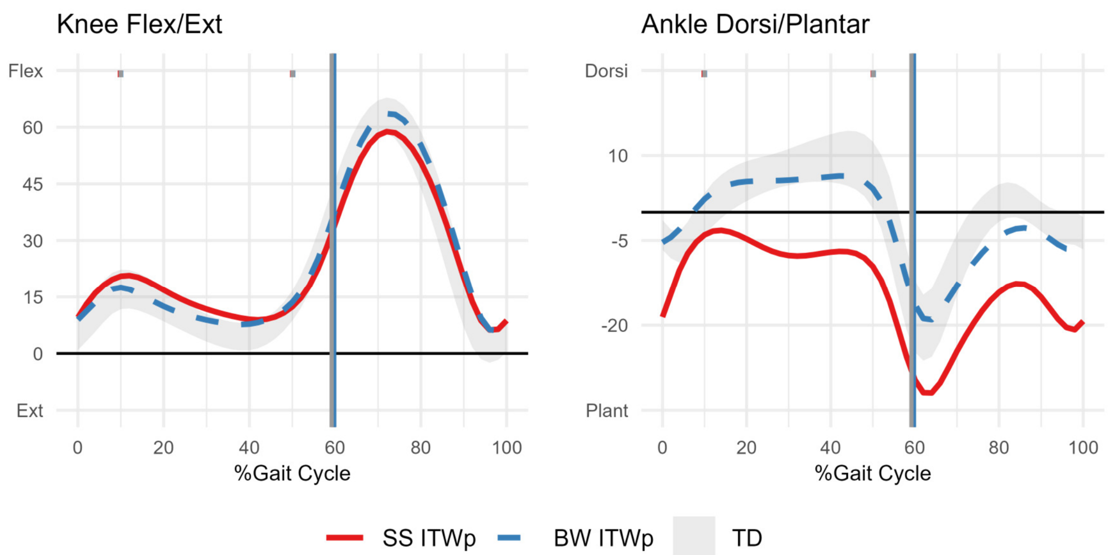

Figure 1. Sagittal plane knee and ankle kinematics for children with persistent idiopathic toe walking in self-selected and best-walk patterns. (ITWp – Idiopathic Toe Walking persistent, SS – Self-Selected, BW – Best-Walk, TD – Typically Developing)

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ACKNOWLEDGMENTS

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DISCLOSURE STATEMENT

J Bauer is a consultant for Orthopediatrics (unrelated to study) and a board member of AACPDM. J Davids is a Board member of the Armstrong Children's Orthopaedic Alliance. M McMulkin, B MacWilliams, and S Sienko have no conflicts of interest to disclose.

Long-term changes in functional and ambulatory status of patients with Myelomeningocele

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INTRODUCTION

Myelomeningocele (MM) is the most severe form of spina bifida[1] causing lifelong disability and caregiver burnout. Although there is a number of studies that focus on the long-term follow-up of the patients with MM, when trying to quantify the qualitative changes observed over time, the description of the progression to-date is not clear. Towards this end, our group introduced the Myelomeningocele Functional Classification Scale (MMFC)[2]. Furthermore, when we introduced it, we advocated that the MMFC and the FMS[3] classification scales are always used together to describe the functional status of patients with MM. Such an approach allows one to have a qualitative and quantitative understanding of each patient's functional level. However, to the best of our knowledge, this new approach has yet to be implemented towards the description of the long-term functional progression of patients with MM.

It is the purpose, therefore, of this investigation to use our approach combined with our motion analysis database to observe and report quantitatively the long-term changes in the functional ambulatory status of patients with MM and identify factors related to these changes.

CLINICAL SIGNIFICANCE

Knowledge of the long-term functional progression of patients with MM would allow health care providers and caregivers of patients with MM to plan more effectively, as well as construct and implement more efficient treatment plans in anticipation of the future functional mobility needs of these patients.

METHODS

Following institutional review approval, a retrospective chart review was performed to identify patients with MM who had a long-term follow-up between January 1970 and December 2022 at our Spina Bifida clinic. Exclusion criteria involved patients with lipomeningocele, meningocele, those younger than 5 years of age, and patients with incomplete data.

One hundred sixty-eight patients with MM were identified (age range 5-52 yo; mean: 20 yo; 52% male, 48% female) and a subset of them (22) had long term follow-up with instrumented gait analysis. From the gait analysis, the functional walking speed (self-selected speed with the ambulatory aids used for everyday walking, such as braces and/or crutches) along with the weight and height to calculate the respective Body Mass Index (BMI) were extracted. From the charts of all identified patients we extracted demographic data, dates of clinic visits, the interventions or surgeries, and patient classification at each visit based on the

MMFC and FMS scales. The gait analysis parameters, based on the first and last gait evaluation, were used to investigate the long-term relationship between MMFC and functional speed and BMI. For that purpose, multiple linear regression analysis was used with significance determined at an alpha of 0.05. The MMFC and FMS classifications, based on the chart reviews with focus on the first and last visit, were used to investigate the long-term changes in functional mobility status of the patients within each function category.

RESULTS

The follow-up time spanned seven to 44 years, with an average follow-up time of 15 years.

Instrumented gait analysis was used for the MMFC2 and MMFC3 classifications as part of both pre-operative and post-operative evaluations or to determine the optimal bracing strategy to achieve the most functional gait. Within this subset of patents, the functional speed had a positive relationship with MMFC that was statistically significant ($p=0.01$) and a negative relationship with BMI that did not reach statistical significance ($p=0.20$). The BMI also had a negative relationship with MMFC which, however, did not reach statistical significance ($p=0.84$).

At the time of first visit 27% of patients were in the MMFC1 classification group, 22% in the MMFC2, 32% in MMFC3 and 18% in MMFC4. By the last visit, 38%, 23%, 24% and 19% were in the MMFC1, MMFC2, MMFC3 and MMFC4 classifications respectively.

DISCUSSION

To the best of our knowledge, this is the first study that describes the long-term functional ambulation changes of patients with MM, along with selected factors related to these changes, based on the MMFC and FMS classification scales combined. Our data suggests that patients in the MMFC1 and MMFC4 groups are stable. However, the ambulatory status of patients in MMFC2 and MMFC3 groups appears to decrease with time, resulting in an increase in patients in the MMFC1 group. Factors related to the changes are surgeries and tethered cord, which cannot be controlled, and BMI and fitness which can be controlled. Functional walking speed is a factor strongly related to the functional status of patients with MM and should be monitored as a sign of the function changes that may be taking place as the patient with MM is aging.

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Spine Motion Deviations in Spondylolysis Patients

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INTRODUCTION

Lumbar spondylolysis is a defect or fracture of the pars interarticularis of the lumbar vertebrae, occurring unilaterally or bilaterally. It is commonly seen in adolescent and young adult athletes and, with repetitive stress, can progress to spondylolisthesis, a condition where the affected vertebra translates anterior relative to the inferior vertebrae.[1]. Both spondylolysis and spondylolisthesis can contribute to acute or chronic lower back pain (LBP), leading to gait alterations and compensatory movement patterns during athletic activities. High-risk movements, such as hyperextension, axial loading, and rotation can exacerbate these conditions [2]. Previous literature suggests that the type and severity of spondylolysis or spondylolisthesis influence spinal mobility [3]. Hypermobility is more common in spondylolysis without vertebral slip, while restricted lateral flexion is observed in both isthmic and degenerative spondylolisthesis. Rotational limitations vary with defect level, and higher grades of displacement tend to increase spinal hypermobility [3].

CLINICAL SIGNIFICANCE

A 3D motion analysis assessment of spondylolysis can help identify compensatory spinal movements, guiding targeted interventions to prevent progression to spondylolisthesis, and optimizing rehabilitation strategies for young athletes returning to sport.

METHODS

Ten adolescent athletes with spondylolysis (SP Group, age 15.9±1.8 years, 60% male) underwent 3D motion analysis at an average of 13.6 months post-injury. Demographic, injury, treatment, and patient outcomes were collected through retrospective chart review. Spinal motion was analyzed using the Wilk multi-segment spine model, which defines *thoracic* motion relative to (r.t.) the lumbar spine, *lumbar* motion r.t. the pelvis, *pelvic* motion r.t. the global coordinate system and *total spine* motion as thoracic motion r.t. the pelvis. The spine protocol consisted of flexion/extension, lateral, and rotation movements of the trunk in a standing position. Statistical analysis was performed using non-parametric Mann-Whitney U tests to compare spinal ROM of those with spondylolysis with typically developing (TD) control data.

RESULTS

Within the SP Group, 65% had acute injuries, while 35% had chronic cases. Injury location was most common at L5 (50%), followed by L4 (30%), and L4/L5 levels (20%). Two participants underwent surgical intervention, one of whom had adolescent idiopathic scoliosis (AIS) and developed spondylolisthesis. On the day of testing, 20% reported LBP.

The SP group showed no noticeable differences during flexion and extension movements when compared to TD (Table 1). SP showed more out of plane forward flexion of the total spine during both lateral bending and rotation towards their injured side. Total spine

ROM was no different when lateral bending or rotating toward their non-injured side (Table 2). Additionally, there was increased lumbar ROM towards their injured side and increased posterior pelvic tilt during the lateral bend. During rotation, the SP group showed increased thoracic ROM in the frontal and transverse plane and increased lumbar flexion on their injured side compared to controls, whereas no difference was seen when rotating toward their non-injured side.

Table 1 – No significant changes in spine motion in spondylolysis group (SP) compared to controls (TD) (p>0.05)

	Total Spine		Thoracic		Lumbar		Pelvis	
	SP	**TD**	**SP**	**TD**	**SP**	**TD**	**SP**	**TD**
Forward Bend								
Sag	51.6 (14.2)	50.2 (19.1)	-10.7 (14.3)	-8.2 (15.6)	62.2 (8.1)	58.3 (9.4)	60.2 (12.7)	56.6 (18.3)
Cor	0.2 (4.4)	-0.1 (5.4)	1.7 (3.6)	0.3 (3.8)	0.4 (3.1)	-0.8 (2.8)	0.9 (1.7)	0.0 (1.9)
Trans	-1.3 (3.3)	-1.5 (5.6)	-0.4 (2.3)	-0.4 (5.1)	0.7 (1.7)	1.4 (2.8)	-1.1 (2.7)	0.7 (4.2)
Forward Tuck								
Sag	67.8 (3.7)	65.2 (15)	5.8 (13.2)	7.8 (11)	62 (8.5)	57.3 (9.1)	58.9 (15.0)	53.6 (16.8)
Cor	-1.4 (5.8)	1.2 (5.4)	-0.7 (3.5)	1.2 (3.5)	0.8 (3.2)	-0.9 (2.6)	1.2 (1.6)	0.2 (2.0)
Trans	-2.8 (4.9)	-1.6 (5.8)	0.5 (3.3)	-1.6 (4.8)	0.2 (2.0)	1.3 (2.8)	-2.3 (3.3)	-1.1 (4.0)
Standing Extension								
Sag	-31.3 (8.7)	-30.4 (9.8)	-12.1 (10.7)	-6.6 (10.9)	-19.1 (8.5)	-23.7 (9.8)	-17.9 (7.0)	-17.0 (7.6)
Cor	1.2 (2.6)	1.9 (3.4)	-0.2 (4.3)	0.5 (3.3)	-0.3 (4.4)	0.2 (2.5)	0.3 (2.0)	0.2 (1.2)
Trans	-0.1 (3.5)	0.2 (3.2)	-0.3 (5.4)	0.8 (3.8)	-0.4 (3.7)	-1.1 (3.2)	-0.1 (3.6)	-0.1 (3.4)

Note: Gray shaded boxes = in plane motion

DISCUSSION

Kinematic analysis revealed increased sagittal out of plane motion during lateral bending and rotation movements. Excessive total spine flexion and lumbar rotation indicate that participants may be using these alternative movement patterns to reduce discomfort. In contrast, reduced sagittal pelvic motion suggests potential stiffness or restricted mobility, which could contribute to altered gait mechanics and increased stress on the lumbar spine. Alterations in thoracic and lumbar rotation suggests additional compensatory strategies in response to restricted lumbar motion or pain. These findings align with previous research indicating that spondylolysis severity and type influence spinal mobility. The observed rotation asymmetry between their injured and non-injured side may reflect an adaptive mechanism to decrease pain or maintain mobility, though further investigation is needed to determine its clinical relevance.

Although some rotational and lateral bending changes did not reach statistical significance, the observed trends highlight key areas for further research. Understanding these compensatory movement patterns is essential for developing targeted rehabilitation strategies aimed at mitigating gait adaptations, reducing pain, and preventing injury progression in young athletes.

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Table 2 – Spine Motion Changes in SP Group on the injured (Inj) vs non-injured (Non-Inj) Side Compared to Control (TD)

	Total Spine			Thoracic			Lumbar			Pelvis		
	Inj	**Non -Inj**	**TD**	**Inj**	**Non-Inj**	**TD**	**Inj**	**Non -Inj**	**TD**	**Inj**	**Non -Inj**	**TD**
Lateral Bend												
Sag	**4.5*** **(7.5)**	5.2 (2.0)	-1.9 (10.8)	-2.9 (7.0)	-6.0 (6.7)	-4.0 (8.5)	7.5 (8.6)	9.7 (8.7)	2.2 (10.8)	**-3.2*** **(4.5)**	-2.7 (3.3)	0.7 (4.4)
Cor	35.2 (5.4)	39.8 (4.7)	34.4 (8.8)	17.9 (6.9)	22.3 (3.5)	17.5 (7.9)	16.8 (5.5)	16.3 (6.6)	15.5 (5.9)	13.3 (4.1)	13.9 (1.4)	15.9 (5.1)
Trans	0.4 (6.6)	4.2 (8.6)	0.2 (8.3)	1.3 (9.6)	5.4 (12.2)	5.3 (11.4)	**0.1*** **(3.8)**	-0.8 (2.8)	-2.5 (4.6)	-1.9 (5.0)	0.9 (4.2)	-1.7 (8.4)
Rotation												
Sag	**2.0*** **(6.9)**	-2.5 (3.8)	-4.8 (7.7)	1.1 (6.3)	-1.1 (2.6)	-1.0 (6.5)	**3.2*** **(6.7)**	1.8 (4.7)	-2.7 (8.0)	2.1 (4.1)	-0.1 (4.1)	3.8 (5.1)
Cor	12.7 (5.6)	4.3 (3.8)	10.1 (7.2)	**12.8*** **(8.2)**	3.6 (2.8)	7.7 (7.5)	-5.0 (4.6)	-7.8 (3.6)	-5.4 (3.4)	-1.0 (2.4)	-0.7 (2.6)	-1.2 (3.1)
Trans	**38.2*** **(8.3)**	35.8 (5.2)	31.5 (10.3)	**40.1*** **(9.6)**	38.1 (8.6)	35.5 (12.1)	0.3 (8.2)	-0.7 (4.8)	-1.8 (4.2)	59.0 (10.8)	55.6 (3.0)	58.1 (16.2)

*Note: * significant difference ($p<0.05$) between injured group and controls; Gray shaded boxes = in plane motion*

MOTOR EQUIVALENCE ANALYSIS OF A NOVEL MINI-SQUAT TASK FROM VARYING INITIAL STANCE CONFIGURATIONS

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INTRODUCTION

The clinical relevance of preferred or optimal movement strategies has in recent years become increasingly scrutinized among physical rehabilitation professionals. Broadly speaking, a traditional perspective might seek to explain pathology in terms of an interplay between physiological lesions and dysfunctional movement. A contrasting and more recent view elevates the role of psychosocial factors in mediating illness experiences and may consider any correlation with tissue or movement anomalies to be unreliable. Often comingled with the debate between these opposing explanatory frameworks one can find substantial miscommunication and terminological inconsistency. In this regard, the nature of optimal movement for specific tasks and individuals is a prime example[1].

Can a movement be considered optimal if it fails to produce an intended outcome? To what extent, if any, is optimal movement common across individuals? While these and similar questions have not been definitively answered, they are given thorough and clinically useful consideration in works on referent control (RC) theory [2]. RC theory describes a process of indirect, parametric control of motor effectors that allows biomechanical equilibrium states to emerge without CNS computation [3]. Importantly, the theory and its associated analytical tools account for the tradeoff between motor behavior optimality and task/outcome stability in a way that may help address the miscommunication between proponents of diverging disease explanatory frameworks.

The purpose of this research was to test the predictions of RC theory regarding the effects of a brief intervening task on steady state motor behavior. We studied the motor equivalent (ME) composition of changes in sagittal plane joint configuration when interrupting bipedal stance with a brief mini-squat task. We repeated these procedures under varying initial positions covering a range of optimal vs. suboptimal configurations. Per RC theory predictions, we hypothesized that 1) ME changes would be minimized when beginning from near-optimal configurations.

CLINICAL SIGNIFICANCE

The meaning of optimal movement for rehabilitative professionals has been obscured by a long history of scientific miscommunication. This study reports measurable effects of theoretical movement optimization phenomena when accounting for the specificity of a given motor task. Our results may ultimately support clinically meaningful measurement, definition, and promotion of healthy movement behaviors.

METHODS

Following consent and task familiarization, twelve healthy adults (24.00 ± 1.48 years, 171.84 ± 14.05 cm, 72.05 ± 11.79 kg) were instrumented for kinematics (VICON; Oxford, UK) and performed a series of “mini-squats” during relaxed bipedal standing in each of three foot placement conditions: 1) feet flat (FLAT, a surrogate for optimal), 2) toes up 12° (TOUP), and

3) toes down 12° (TODO). During each 5 min. trial, an auditory metronome cued participants every 15 s to squat by bending from the hips, knees, and ankles. Trials within a 95% confidence limit of each participant's standardized squat depth were retained for analysis.

Raw data were used to compute sagittal plane angles for the ankle, knee, hip, thoracolumbar junction (TLJ), and neck, as well as anteroposterior displacement of the total body center of mass (COM). We then performed an uncontrolled manifold analysis on the static portion of the bipedal standing data preceding each mini-squat. In this analysis, combined joint motion was projected onto two subspaces, one keeping COM unchanged ("null space") and an orthogonal complement. ME deviation was then quantified as the null space projection of the joint configuration difference between pre- and post-squat time instants. Effects of stance condition on the magnitude of ME was assessed using a robust, linear mixed effects model with random effects for participant (*a priori* $\alpha = 0.05$).

RESULTS

Normalized ME variance by condition was as follows: FLAT = 1.76 ± 0.20, TODO = 1.66 ± 0.20, TOUP = 1.99 ± 0.20. Fixed effects estimates (reference condition: FLAT) are shown in Table 1. Pairwise testing indicated differences for FLAT vs. TOUP [$z = -3.94$, $p < 0.01$] and for TODO vs. TOUP [$z = 5.60$, $p < 0.01$]. The FLAT vs. TODO comparison was *ns*.

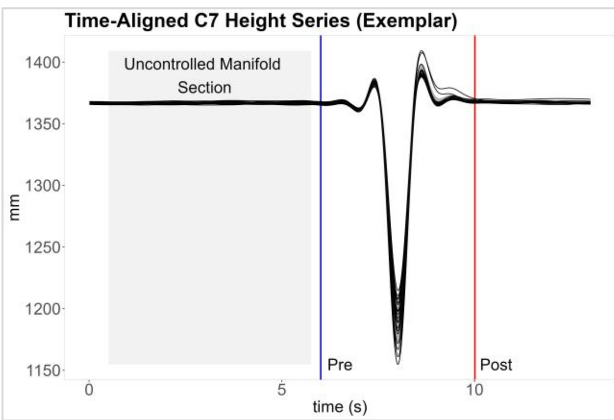

Table 1

Effect	**Coeff.**	**t**	**p<**
(Int)	1.76	9.00	0.01
TODO	-0.10	-1.70	0.09
TOUP	0.23	3.94	0.01

Conditional R^2 = 0.02; Marginal R^2 = 0.30

Figure 1. Vertical displacement (C7) associated with mini-squat task at 15 s intervals.

DISCUSSION

Our findings indicate that ME deviation of relaxed bipedal standing, when interrupted by a transient task, may be greater when beginning from non-preferred configurations. This observation is consistent with the predictions of referent control theory and may help address ambiguity concerning the nature of optimal movement that has thus far limited the clinical utility of this construct. The direction-specificity of these effects will require further study.

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DISCLOSURE STATEMENT

The authors report no conflicts of interest to disclose.

A Cluster Analysis on Trunk and Pelvic Kinematics in Children with Diplegic Cerebral Palsy

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INTRODUCTION

Flexed knee gait is common in children with cerebral palsy (CP). Increased anterior pelvic tilt is a commonly reported undesirable outcome of orthopedic surgeries utilized to optimize such gait pattern and is a cause for concern. Lower limbs, pelvis, and trunk work synchronously to maintain an upright posture in standing and gait. Malalignment of the pelvis in the sagittal plane is thought to result in compensatory gait and posture mechanisms in the lower limbs and spine alignment, which have the potential to compromise gait and quality of life further. Such interactions have attracted scarce research interest in the field of cerebral palsy. This study used cluster analysis of the sagittal plane, including pelvis and trunk kinematics, and assessed several identified associations in a cohort of ambulatory children with cerebral palsy.

CLINICAL SIGNIFICANCE

Children with CP who may be at risk of developing increased anterior pelvic tilt can be identified using cluster analysis, which may help clinicians with treatment planning.

METHODS

Data from 71 children (7-17 years old) diagnosed with CP GMFCS level II who presented for gait analysis at an accredited motion laboratory was retrospectively analyzed in this IRB-approved study. Data from 50 typically developing (TD) children from the laboratory database were collected as a reference. 3-D motion data (marker trajectories, ground reaction forces) were collected, and spatiotemporal parameters, kinematics, and power were calculated with commercially available software for a minimum of 3 walking trials. TD data was used to evaluate clustering accuracy. Hence, we filtered TD data to minimize variability based on the following criteria: 1) knee flexion (>10 deg.) at initial contact and 2) pelvic tilt within group mean±0.5SD. Only 19 TD children (7-17 years old) were considered for final analysis.

Among stance sub-phases (loading response, early mid-stance, terminal mid-stance, and pre-swing), a single sub-phase was identified for our analysis. In TD, the frequency of occurrence in maximum values of anterior pelvic tilt was used to determine this sub-phase. Average gait parameters during the sub-phase were analyzed. A sparse k-means cluster analysis [6] was performed on sagittal plane pelvic and trunk kinematics from CP and TD children. Wilcoxon signed-rank tests with Bonferroni correction ($\alpha = 0.008$) assessed cluster differences.

RESULTS

In TD children, the maximum value of pelvic tilt occurred in the terminal mid-stance, and this phase was considered for analysis. Sparse k-means analysis found 4 clusters in our TD and CP data.

Among TD, average pelvic and trunk tilt were 10.6± 2.3° and 2.1 ± 4°, respectively. Average pelvic tilt was 21.4 ± 3.2, 15.9 ± 3.5, 10.5 ± 2, and 0.8 ± 3.1 degrees for clusters 1, 2, 3, and 4, respectively. Pelvic tilt was significantly different between clusters ($p < 0.001$).

Average trunk tilt was 2.9 ± 4.6, 12.7 ± 5.0, 1.8 ± 3.5, and 2.4 ± 4.5 degrees for Clusters 1, 2, 3, and 4, respectively. Trunk tilt was similar between Clusters 1, 3, and 4 but significantly different from Cluster 2 ($p < 0.001$).

There were no differences in spatiotemporal parameters and knee/ ankle kinematics between the clusters. However, hip flexion significantly differed between Clusters 1, 3, and 4 among CP. Average Hip flexion during the stance subphase was 13.5 ± 10.0, 11.0 ± 7.2, 2.7 ± 9.3, and 4.1 ± 6.8 deg. for Clusters 1, 2, 3, and 4, respectively.

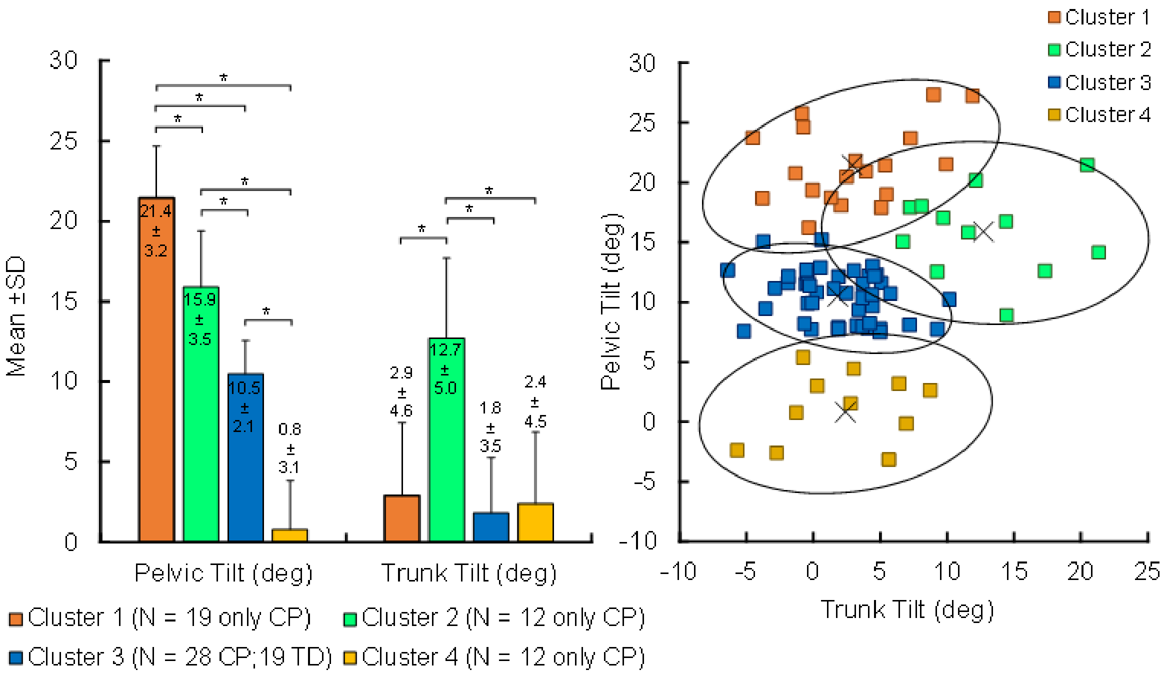

Figure 1. Pelvic and trunk tilt differences and cluster distribution with 90% confidence ellipsoids.

DISCUSSION

Our cluster analysis stratified children with CP at GMFCS level II based on anterior pelvic tilt. An increased anterior pelvic tilt was observed in 31/71 children with CP, which was accompanied by an increased trunk tilt in 12 children. Factors contributing to these adaptations need further investigation.

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Effect of Talocalcaneal Coalitions on Foot and Ankle Kinematics in Adolescents

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Introduction

Talocalcaneal coalitions are one of the most common tarsal coalitions diagnosed in adolescent patients[1-3]. It occurs when an abnormal connection, either osseous or fibrous, forms between the talus and calcaneus, limiting subtalar motion[1-3]. The coalition can continue to ossify as patients reach skeletal maturity which causes various symptoms prompting them to seek clinical care[3]. These coalitions can cause rigid flatfeet, pain, lead to ankle sprains, and other factors affecting daily living[1-3]. Aside from clinical examination, gait analysis is useful in providing information about how segments move in relation to one another during gait. Multi-segment foot models have been on the rise to accurately analyze segments of the foot since most general models assume the foot to be a single rigid body. It is known that talocalcaneal coalitions limit or reduce subtalar motion, but it is important to understand how it may also impact various segments of the foot during gait.

Clinical Significance

Reduction of subtalar motion mostly affects function of the hindfoot during gait, but further analysis is needed to understand resulting compensatory patterns that hinder function. Analysis of foot kinematics during initial presentation can set the foundation to determine what aspects may warrant conservative or surgical treatment.

Methods

The study consisted of a retrospective review of patients from an IRB approved foot and ankle registry. Eleven participants (17 feet) had a confirmed talocalcaneal coalition diagnosis. Fifteen controls (26 feet) were used as the comparative control cohort. All participants underwent gait analysis using a Vicon Motion Capture System. A modified Helen Hayes marker set was used in addition to our SRC foot model to analyze different foot segments relative to one another during gait. The SRC foot model allows motion analysis of the hindfoot segment relative to the tibia, and the forefoot segment relative to the hindfoot. A representative trial was chosen from a set of consistencies for analysis. Statistical analysis was completed by using a non-parametric Mann Whitney U test with $p<0.05$.

Results

Table 1 shows the results for the kinematic variables involving the ankle, hindfoot relative to the tibia, and the forefoot relative to the hindfoot.

Discussion

General ankle motion shows that feet with talocalcaneal coalitions exhibit reduced sagittal plane motion and a more external foot progression angle. Hindfoot motion relative to the tibia shows that the hindfoot in the coalition group remains slightly dorsiflexed during push-off in 3rd rocker. The coalition group also remains in hindfoot valgus during stance with reduced range of motion in the coronal plane. There were significant differences in all kinematic variables amongst all planes of motion when looking at the forefoot relative to the hindfoot. Most notably there is increased plantarflexion seen throughout all three rockers of gait, increased inversion, and increased forefoot abduction. These can be considered compensatory motions to maintain a functional foot while the hindfoot motion is limited.

Table 1: Ankle and foot segment kinematics in the sagittal, coronal, and transverse planes.

		Normal (n=26)		Talocalcaneal (n=17)		
Plane	**Variable**	**mean**	**sd**	**mean**	**sd**	**p-value**
Ankle						
Sagittal	Range of Motion	32.88	7.66	27.64	6.43	0.022
Sagittal	1st Rocker	-7.41	3.01	-8.45	3.53	0.396
Sagittal	2nd Rocker	14.27	2.95	12.60	3.11	0.035
Sagittal	3rd Rocker	-9.45	6.55	-3.66	10.71	0.004
Transverse	Position During Stance	10.65	10.55	8.97	9.24	0.547
Transverse	Foot Progression Angle	-7.07	7.33	-18.17	10.74	0.001
Hindfoot Relative to Tibia						
Sagittal	Range of Motion	21.40	4.91	22.89	3.96	0.306
Sagittal	1st Rocker	-5.62	3.65	-5.41	3.74	1.000
Sagittal	2nd Rocker	11.50	3.43	13.90	4.94	0.076
Sagittal	3rd Rocker	-3.24	5.12	3.50	9.23	0.002
Coronal	Range of Motion	10.25	2.32	6.84	2.28	< 0.001
Coronal	Position During Stance	-3.82	3.40	-8.08	5.60	0.003
Transverse	Range of Motion	14.82	3.56	15.19	3.74	0.893
Transverse	Position During Stance	13.28	10.82	15.71	7.47	0.343
Forefoot Relative to Hindfoot						
Sagittal	Range of Motion	15.47	5.02	11.60	3.55	0.013
Sagittal	1st Rocker	-3.50	4.44	-9.37	5.28	0.001
Sagittal	2nd Rocker	5.37	4.96	-2.62	5.53	< 0.001
Sagittal	3rd Rocker	-7.52	5.60	-11.71	4.98	0.012
Coronal	Range of Motion	11.28	3.32	14.41	3.65	0.011
Coronal	Position During Stance	4.72	4.52	9.81	6.56	0.004
Transverse	Range of Motion	9.59	3.03	6.01	3.15	<0.001
Transverse	Position During Stance	-14.94	6.21	-22.71	8.61	0.004

*All values are in degrees
**PF=Plantarflexion; DF=Dorsiflexion; Ext=External; Int=Internal; Val=Valgus; Var=Varus; Ever=Eversion; Inv=Inversion; Abd=Abduction; Add=Adduction
***Postive value = dorsiflexion (sagittal), inversion/varus (coronal), internal/adduction (transverse)

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The authors have no disclosures.

Concurrent Validity of Modern Motion Analysis Tools for Reachable Workspace Assessment

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INTRODUCTION

Advancements in motion capture, such as human pose estimation (HPE) and virtual reality (VR), have made rehabilitation more accessible by reducing the setup and processing burdens of traditional systems [1]. These technologies will be particularly useful in pediatric rehabilitation through the incorporation of "gamification," which enhances patient engagement and interaction with therapy tasks [2]. One important clinical application is the assessment of upper extremity (UE) outer reachable workspace (RW), which objectively quantifies UE mobility and offers critical insights into patient quality of life. Traditional RW assessments rely on subjective clinician evaluations, but the use of motion tracking systems with real-time interactive feedback offers a more efficient and objective approach, though complex setups and expert operation still pose challenges.

The purpose of this work is to provide a concurrent validation of markerless motion capture and VR systems for clinical use in patients with brachial plexus palsy. We demonstrate the application of Theia3D, a commercial markerless motion capture system, alongside a custom VR system for measuring reachable workspace, comparing results to modified outputs from previous work. The novelty of this study lies in several key aspects: we concurrently obtained both VR, markerless, and marker-based motion data during upper extremity reachable workspace trials in able-bodied individuals.

CLINICAL SIGNIFICANCE

We demonstrate the concurrent validity of VR and Theia3D with marker-based motion capture for a clinical assessment of upper extremity reachable workspace.

METHODS

Nine healthy adults (5 males, 4 females) with a mean height of 1.69 ± 0.09 m and a mean mass of 70.56 ± 19.05 kg participated in this study. Data was collected using a Quest 3 HMD, a Vicon motion capture system, and a FLIR system, with the VR system providing visual feedback. The collected data was processed with temporal mapping and a moving average filter to smooth the VR data. The marker-based, Theia3D, and VR coordinate systems were adapted and aligned to assess upper extremity reachable workspace, with each system tracking wrist motion and using specific vectors to define the coordinate axes for comparison. The reachable workspace was calculated using an adapted method from [3]. Targets were reached if the end effector was > 50% of the distance from the origin to the maximal reach distance.

Data were analyzed with the RMSE between the end effector wrist position as measured by marker-based, markerless and VR based motion capture. We then completed a Bland-Altman analysis of the overall differences between both VR, Markerless and Markerbased motion capture system for each participant and each octant.

RESULTS

We examine the total number of targets reached per octant, as the measure of reachable workspace. We show that both the Theia3D system and VR consistently underestimate the number of targets reach in each octant, and there is greater variability in the errors in from the VR system than with the Theia3D system (18.80 compared to 13.25).

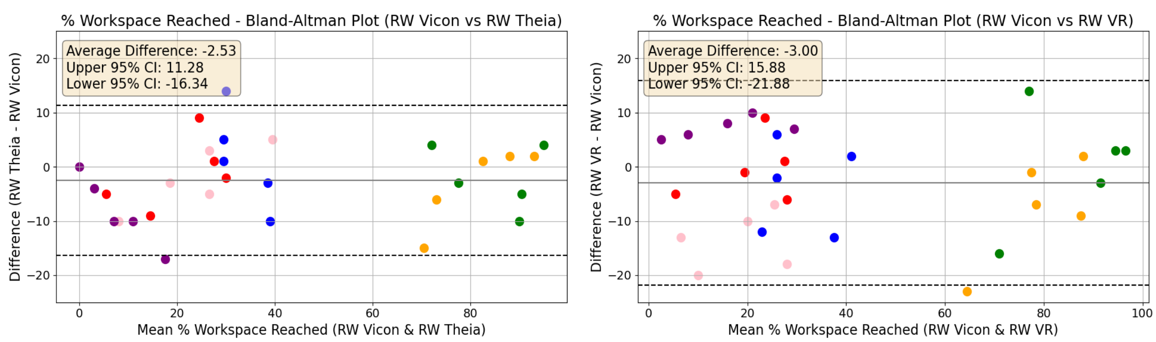

Fig. 1 Bland Altman plots for each of the data collection methods, the Vicon based method compared to both the Theia3D and the VR reachable workspace calculations. Each of the dots represents a participant and each of the colors are a specific octant.

DISCUSSION

This study aimed to compare VR and markerless motion capture systems for assessing reachable workspace in a clinical context. Our findings show that data from the Theia3D system closely aligns with the marker-based system, exhibiting a bias of -2.53 ± 13.25 targets per octant, while the VR system demonstrated greater bias (-3.00 ± 18.80 targets per octant) across all targets. Overall, both systems showed good agreement with the marker-based motion capture. The reduced performance of the VR system may be attributed to participants being instructed to look straight ahead during the assessment. Similarly, the accuracy of the Theia3D system may have been impacted using only eight cameras compared to the twelve used in the marker-based setup.

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DISCLOSURE STATEMENT: Authors have nothing to disclose

IS GAIT SYMMETRICAL IN PATIENTS WITH HEREDITARY SPASTIC PARAPLEGIA?

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INTRODUCTION

Hereditary spastic paraplegia (HSP) describes a rare group of neurologic disorders that result from a genetic etiology. To date there are more than 90 different genotypes which result in a rather heterogeneous HSP population. Patients primarily present with bilateral lower extremity spasticity and weakness as a result of degeneration of the corticospinal tracts. These impairments result in various gait abnormalities [1].

It is unclear if this degeneration impacts the right and left sides symmetrically. Asymmetry is the amount of divergence between the left and right sides of the body, often associated with pathology, but present to a degree as a result of limb dominance [2,3]. The neuromuscular examination of patients with HSP can be extensive. Comparisons of left- and right-sided findings can be quite difficult to conduct due to the sheer volume of information obtained.

CLINICAL SIGNIFICANCE

Human gait is an extremely complex act which requires interaction between the central nervous system and segments across the kinematic chain of the body. Three dimensional gait analysis (3DGA) can provide objective data about a patient's functional mobility, as well as their gait symmetry. By using a comprehensive score based on this kinematic data such as the Gait Deviation Index (GDI) or the Gait Profile Score (GPS), it is possible to assign a value for each lower limb [4]. This in turn may help understand the degree of symmetric involvement of the corticospinal tracts. Additionally, when using the GDI or GPS it is important to know if values for the left and right are close enough to use a mean of the two as a representative value to describe the patient's overall gait.

METHODS

A retrospective review of data was conducted from genetically confirmed patients enrolled in a prospective HSP study. Patients needed to be functional ambulators, have had no surgery on either lower extremity, and have completed 3DGA. Forty patients met all requirements. Gait data were processed and GDI, GPS, associated Movement Analysis Profile (MAP), and cadence parameters were completed for each extremity. Statistical analysis was then performed.

The Symmetry Index (SI) [5] was used to compare left/right GDI, GPS, MAP scores, and left/right cadence parameters; additionally, Spearman's Rank Correlation was also used. The SI is calculated as the absolute value of the right variable minus the left variable, divided by one-half times the right variable plus the left variable, times 100. Therefore, the SI indicates that the values for the right and left differ by the resultant percentage relative to their average value [5]. As a result, if the difference between two numbers is small, and the average of those two numbers is also small, the SI can be relatively large. Gait symmetry is considered to be at an acceptable level when the SI value is $<10\%$ [6].

RESULTS

The mean patient age at time of collection was 10.37±5.66 years. Table 1 shows both acceptable symmetry values as well as very strong correlations (>0.85) for the GDI, Step Time, Step Length, and Double Support Time. Single Support Time also shows an acceptable symmetry value with a good correlation. Symmetry for the GPS is considered good, and also has a strong correlation. Mann-Whitney comparisons failed to identify significant differences between genders, age groups, or different genotypes.

Symmetry of Gait Function in Confirmed HSP (n=40)				
Gait Variable:	Value: Left	Value: Right	SI %	rho (p-value)
GDI	67.10	69.93	9.21	0.88 (<0.0001)
GPS	11.18	10.54	15.35	0.89 (<0.0001)
Cadence Parameters:				
Step Time	115.68	117.03	5.85	0.85 (<0.0001)
Step Length	84.20	83.93	6.46	0.93 (<0.0001)
Single Support %	94.73	94.35	5.17	0.62 (<0.0001)
Double Support %	124.10	125.85	7.96	0.92 (<0.0001)

Table 1: Comparison between gait variables including the Gait Deviation Index (GDI), the Gait Profile Score (GPS), and cadence parameters on the left and right sides of patients with Hereditary Spastic Paraplegia (HSP). Comparisons were completed using the Symmetry Index (SI) for all variables, as well as Spearman's Rank Correlations (rho) $p < 0.05$.

DISCUSSION

Despite known heterogeneity within the HSP population, the conclusion that gait is identified as objectively symmetric supports the idea that the involvement of the corticospinal tracts is also symmetric. Additionally, the relative symmetry between left and right sides supports the use of a mean value for the GDI or GPS when only one gait score is preferable within research uses. While good to acceptable SIs and moderate to strong correlations were identified for GDI and GPS scores as well as cadence parameters, the decreased symmetry identified across the various MAP scores indicates increased variability across joints and/or planes of motion. Therefore, it is important to keep in mind that overall gait scores created through a consolidation of kinematic data may hide the smaller asymmetries present throughout a heterogeneous group such as with HSP.

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DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

Overlooking knee height asymmetry: Is there functional consequences?

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PATIENT HISTORY

The patient was seen at eleven-year-old for fibular hemimelia and leg length discrepancy at our tertiary orthopedic pediatric hospital. At that time, she complained primarily about difficulties with her shoe lift, reporting some ankle instability and a tendency to twist her ankle whenever she wears the lift. Additionally, she engaged in many sports activities and did not wear the lift during these activities.

CLINICAL DATA

On physical examination, a clinically apparent leg length discrepancy of 4 cm was present. There was a 20 mm shorter femur and 20 mm shorter tibia on the left leg. The range of motion in the knee and ankle was normal and symmetrical. The hips showed no abnormalities. Patient was otherwise healthy.

MOTION DATA

Biomechanical data were collected using a marker-based motion capture system with 10 cameras and 4 force plates in a pediatric tertiary orthopedic hospital in Canada. Kinematic and kinetic data from the pelvis, hip, knee, and ankle joints in the transverse, sagittal, and frontal planes were recorded during barefoot walking, and during two-legged squats and jumps. These data were analyzed to identify gait and biomechanical asymmetries.

TREATMENT DECISIONS AND INDICATIONS

Given her difficulty tolerating the lift and the parents' request to address the current discrepancy, options such as shoe lifts, contralateral epiphysiodesis, and segment lengthening were suggested. Given the problems with the shoe lift and the high activity level of the patient, it was decided to lengthen the left femur by 40 mm. This resulted in a longer left femur and a shorter ipsilateral tibia, leading to a difference between the left and right knee height of 20 mm (see Figure 1 C).

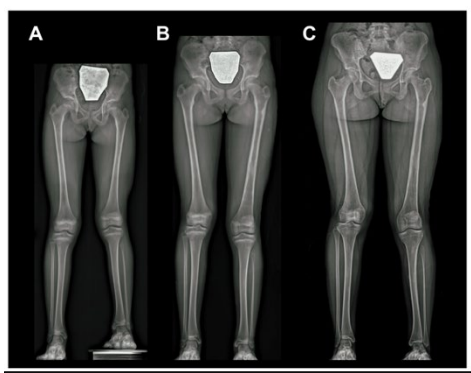

Figure 1: A-Pre-lengthening surgery; B-One year post-lengthening surgery and C-Four years post-lengthening surgery X-rays.

This is called Knee Height Asymmetry (KHA). KHA is a condition where one knee joint is positioned higher than the other due to misalignment in the coronal plane, with or without an associated leg length discrepancy (LLD) [1]. This difference in lower limb segments length leads to variations in lever arm lengths, potentially influencing the moment of force (kinetics) and joint angles (kinematics) at the lower limbs, thereby altering biomechanics [2, 3].

OUTCOME

These results are obtained nine-years post op where the patient presented with a 20 mm KHA on the left leg and a corrected LLD.

For gait, only minor asymmetries in the coronal plane were observed, with maximum pelvic obliquity and hip adduction differences between sides being less than 7 degrees.

Asymmetries were more pronounced during functional tasks than during gait. Squatting and jumping revealed asymmetries in two planes of motion. The largest asymmetries were for hip and pelvic rotations, where differences between sides reached up to 15 degrees. For instance, during squats, right hip rotation varied from 5 to 15 degrees externally, while the left side (with the longer femur) ranged from 10 degrees internal to 20 degrees external (Figure 2). Similarly, during jumping, pelvic rotation asymmetries reached up to 12 degrees.

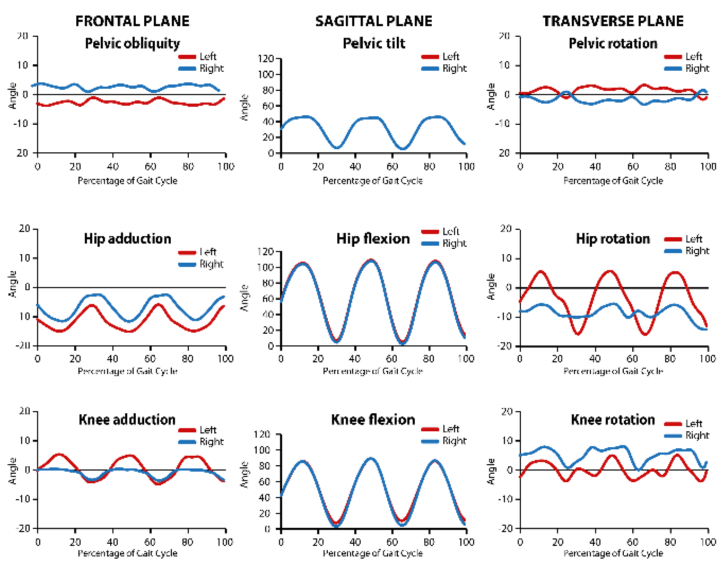

Figure 2: Kinematic curves for 3 consecutives two-legged squats.

SUMMARY

This case highlights the importance of motion analysis in understanding the biomechanical impact of a 20 mm KHA. While gait asymmetries were minimal and confined to the coronal plane, dynamic activities like squatting and jumping revealed compensatory strategies, particularly in hip and pelvic rotation. These findings emphasized the need to supplement gait analysis with demanding functional tasks to better identify biomechanical challenges. Unanswered questions remain regarding the long-term effects of these compensatory patterns on joint health and the threshold at which functional impairments become clinically significant. Further research is needed to explore how larger KHA and targeted interventions, such as physiotherapy or corrective surgery, influence the risk of overuse injuries or osteoarthritis.

DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

Pre-Post Surgery Outcomes of a Patient with Hurler Syndrome

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PATIENT HISTORY

A 9-year-old female with a crouch gait and bilateral knee pain, a history of Mucopolysaccharidosis Type 1 H-S, spondylolisthesis C7-T1, bilateral acetabular dysplasia, kyphosis at the thoracolumbar junction, and Camptodactyly with Madelung deformity was followed. Upon assessment, she presented difficulty and fatigue with walking, running, and stair climbing.

CLINICAL DATA

Computed Radiography of the lumbar spine showed a 21° right convex scoliosis from L2 to L5, thoracolumbar kyphosis, straightening of the lumbar spine, and right hemipelvis 1.4 cm lower than the left. There was a broadening of the anterior ribs consistent with Hurler syndrome. A computed radiography bone length study revealed a right lower extremity length of 49.6 cm and a left lower extremity length of 50.7 cm, mild valgus of the left knee, medial downward tilt of both talar domes with inward valgus alignment of ankles. She had a valgus deformity of bilateral hips with lateral exposure of both femoral heads and elongated femoral necks with decreased diaphyseal cutback at the metaphyseal centers of the distal femurs and proximal tibia.

The clinical exam revealed bilateral hip flexion contractures of 5° from neutral, bilateral knee flexion contractures of 40° from neutral, and hamstring shifts of 40° on the left and 35° on the right with the hip at 90°. There was a mild increase in hamstrings, quadriceps, and gastrocnemius-soleus tone.

She presented with lower-than-normal results on the Pediatric Outcomes Data Collection Instrument (PODCI) in all domains, including Upper Extremity and Physical Functioning (33/100), Transfers and Basic Mobility (52/100), Sports and Physical Function (53/100), Pain and Comfort (64/100), Happiness (45/100), and Global Functioning (51/100).

MOTION DATA

The patient underwent pre-operative and three-year post-operative gait analysis using a modified Helen-Hayes gait model. Pre-operatively, she has bilateral external foot progression angles, left hemipelvis protraction in late stance, and right retraction throughout the gait cycle, increased bilateral hip flexion, increased bilateral knee flexion in stance and swing, increased ankle plantarflexion at initial contact, and decreased dorsiflexion in stance with blunted peak plantarflexion (R>L), and increased bilateral hip abduction in stance (L>R) as shown in **Figure 1**.

TREATMENT DECISIONS AND INDICATIONS

Following her gait analysis, the patient underwent bilateral proximal femoral extension varus shortening osteotomies, bilateral common peroneal nerve release, bilateral proximal tibial extension osteotomies with fibular osteotomies, bilateral distal femoral shortening extension osteotomies. Physical therapy was attended for 14 months following surgery.

OUTCOME

On physical assessment at three years post-surgery, the patient demonstrated improvements in hip extension, achieving 10° bilaterally, and improved knee extension, achieving 0° bilaterally.

For the PODCI, she had improvements in the Upper Extremity and Physical Functioning (Pre: 33, Post: 57), Transfers and Basic Mobility (Pre: 52, Post: 59), and decreases in the Sports and Physical Function (Pre: 53, Post: 27), Pain and Comfort (Pre: 64, Post: 37), Happiness (Pre: 45, Post: 37) and Global Functioning (Pre: 51, Post 45).

Kinematic results showed improvements towards normal in the frontal plane for knee flexion during mid-stance on the left and elimination of normal bilateral plantarflexion at initial contact. Improvements were noted in the transverse plane with grossly normal bilateral foot progression angles. Kinetic results showed improvements in bilateral knee extension moments during stance. She also improved GDI scores pre- to post-surgery (L: Pre: 51.2 Post: 80 and R Pre: 51, Post: 71.8).

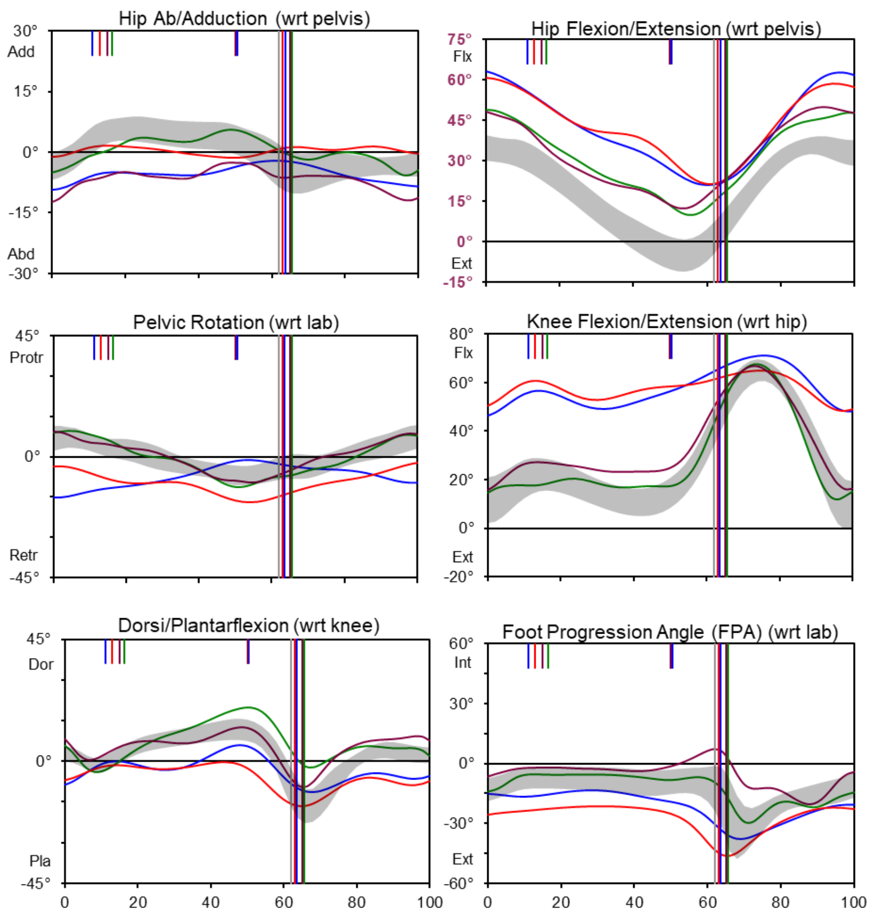

Figure 1 shows pre- and post-surgical kinematics for hip abd/add, hip flex-ext, pelvic rotation, knee flex-ext, ankle dorsi/plantar flexion, and foot progression angle. (Left Pre-Surgery Left Post-Surgery Right Pre-Surgery Right Post-Surgery)

SUMMARY

This case study on a young patient with Hurler Syndrome showed that the surgical treatment efficiently restored function, normalized gait patterns, and reduced bilateral knee and hip flexion contractures. It highlights the utility of 3D gait analysis for pre-surgical planning and post-operative outcomes assessment for ambulatory children with Hurler syndrome.

DISCLOSURE STATEMENT

The authors have no conflict of interest to disclose.

The Clinical Utility of Knee Walking
in Identifying Compensatory Movement Patterns

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PATIENT HISTORY

The patient was a 13-year-old female diagnosed with spastic quadriplegic cerebral palsy (CP, GMFCS level 2) and scoliosis of a neuromuscular etiology. She was able to independently ambulate, with a FMS score of 5 at shorter distances, but used a manual wheelchair for medium to longer distance due to poor endurance. Medical history reported no use of spasticity management medications, or surgical orthopedic interventions. She was referred to the motion analysis lab for determination of proper lower extremity orthotics.

CLINICAL DATA

Physical exam revealed 20° limitations in maximal knee extension and 15° limitations in ankle dorsiflexion. Spasticity was noted bilaterally in the hamstrings, posterior tibialis, and peroneals, as assessed using the Modified Tardieu Scale. Static standing alignment showed calcaneovalgus, more pronounced on the right side. Strength testing could not be performed due to the patient's difficulty following instructions for manual muscle testing.

Recent radiographs, taken near the time of assessment, showed a 50° thoracolumbar curve (Lenke 5) along with reduced thoracic kyphosis and lordosis. Standing pelvic obliquity was measured at 14°, with the left hemipelvis higher than the right.

MOTION DATA

Over ground (OG) and knee walking (KW) trials at a self-selected velocity were captured by a passive optical motion capture system, sampling at 100Hz. 3D kinematics were derived from marker positions using a modified Helen Hayes configuration.

She exhibited a crouch gait pattern during OG with excessive knee flexion and ankle dorsiflexion (Figure 1). In sagittal plane there was fixed hip flexion, with anterior pelvic tilt. She also demonstrated left lateral trunk lean, with 10° of fixed pelvic obliquity (left side up), and associated left hip adduction/right hip abduction. During KW, mean hip flexion during stance decreased 9°, accompanied by a reduction in overall ROM, despite no change in pelvic tilt position or ROM. In the coronal plane there was increased lateral trunk excursion, with reduced fixed pelvic obliquity and increased pelvic ROM. Additionally, trunk and pelvic rotation ROM increased during KW.

SUMMARY

The purpose of KW was twofold: (1) to assess core and hip strength, as the primary segments involved in stability and forward progression, and (2) to eliminate the distal deformity from the kinetic chain, allowing identification of secondary and compensatory deviations caused by improper weight acceptance or segment posture.

The patient exhibited a crouch gait pattern, primarily driven by knee flexor spasticity and calcaneovalgus foot deformity, which limited the ability of the plantarflexors to control tibial progression during the stance phase. It is important to note that a rigid body foot model may overestimate ankle dorsiflexion in the presence of severe calcaneovalgus.

By removing the segments distal to the hip joint, the patient was able to adopt a more upright posture, as evidenced by the changes in hip flexion between the two conditions. In the coronal plane, minor reductions in pelvic obliquity were observed, and the left ipsilateral trunk lean seen in overground walking trials was nearly neutralized during KW. Although both pelvic obliquity and ipsilateral trunk lean may be partially attributed to the patient's scoliosis, these findings suggest that the increased pelvic obliquity in overground walking was partly due to the loading of the asymmetrically flexed/dorsiflexed joints distally. The left trunk lean, in turn, may be a compensatory mechanism to shift the center of mass and unload the more affected (right) limb during stance. Increases in trunk and pelvic rotation range of motion (ROM), along with decreases in sagittal hip ROM, suggest an altered movement pattern that relies more on transverse kinematics for forward progression.

Given the multisegmental and multiplanar complexity of gait, it is essential to isolate the biomechanical effects of primary deviations to better understand their impact on secondary or compensatory deviations. This approach is key to developing more targeted interventions.

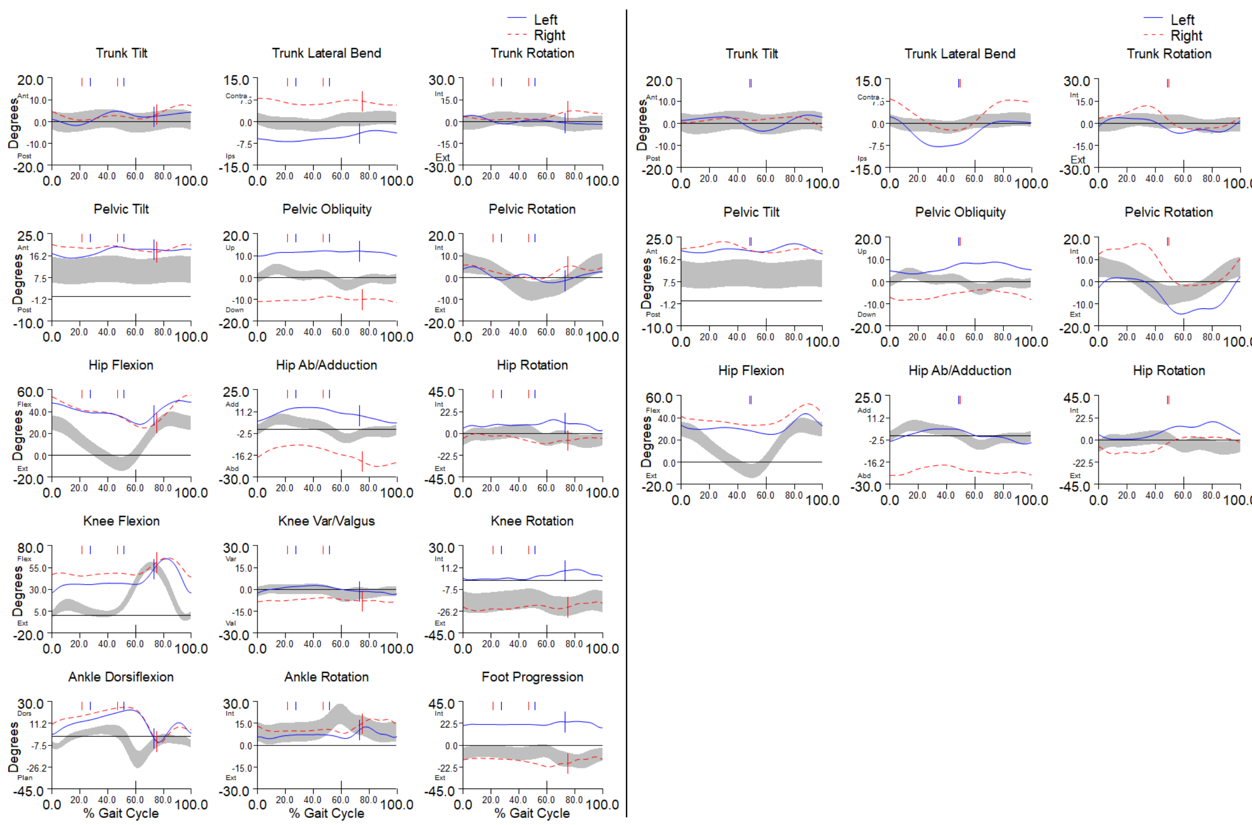

Figure 1. Over Ground Walking (left) and Knee Walking (right) Kinematic Data

DISCLOSURE STATEMENT

Kirsten Tulchin-Francis is a co-chair for the 2025 GCMAS meeting.

Effects of Twister Cables on the Malalignment of the Lower Extremity in Children with Gait Disorder

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INTRODUCTION

In-toeing and out-toeing gait are clinical symptoms arising from anatomic dysfunction in neuromuscular disorders (NMD), such as in cerebral palsy (CP) and spina bifida (SB) [1-3]. Multiple orthotics are a commonly used conservative treatment for gait correction, including Twister Cables (TC), and ankle-foot orthotics (AFO) [4]. There have been limited studies on the efficacy of TC regarding its efficacy on lower extremity joint correction.

CLINICAL SIGNIFICANCE

Understanding how Twister Cables impact the rotation of the pelvic, hip, knee or ankle joint in the transverse, coronal, and sagittal planes, can guide clinicians in effectively improving foot progression angle (FPA) correction in children with neuromuscular conditions.

METHODS

This study was a retrospective design based upon the chart review and gait analysis reports approved by MCW IRB. Inclusion criteria: children with NMD who received TC and/or AFO for abnormal gait and underwent motion analysis at the Center for Motion Analysis, Children's Wisconsin, MCW from 1/1/2013 to 06/3/2024. Gait analysis data were collected for walking with barefoot, with TC +AFO (using abbreviation as “TC”), or with AFO per patient, respectively. The 3D joint motions of the lower extremity and spatio-temporal data (T-S) were captured by using the Plug-in-Gait Model with 12 cameras (Vicon MX, Oxford, UK) and were divided into stance phase (ST) and swing phase (SW) of GC.

RESULTS

There are no significant differences were seen in T-S and GDI between TC and barefoot (P>0.05). Significant differences are seen in lower extremity (LE) transversal rotations between TCs and barefoot (P<0.05), including increased hip range of motion (ROM) at 0-30% GC and SW, reduced ankle ROM at 0-30% GC, mean ST, and SW for TC. Significant differences are seen in LE transversal rotations between TC and AFO (P<0.05), including reduced pelvic ROM at 51-60% GC, increased hip ROM at 0-30% GC and mean ST, reduced knee ROM at 31-50% and 51% to 60% GC, reduced peak FPA at 0-30% GC, 31-50% GC, mean ST, respectively, and reduced FPA-ROM at mean SW for TC. Significant differences are seen in LE transversal rotations between AFO and barefoot ($P<0.05$), including increased hip ROM at SW, increased knee ROM at 31-50% GC, and increased FPA ROM at SW for AFOs.

DISCUSSION

TC combined AFO provides a strong de-rotational mechanism at the hip joint level but decreases the mechanical force generated at the ankle. Significantly reduced ankle ROM during the most of GC implies that this combined device improves ankle malrotation but limits improvement in FPA. In comparison, AFO alone worsens malrotations in the transversal plane at hip, knee and FPA as compared to barefoot. This may further suggest that TC alone provides pronounced de-rotational mechanism to improve the malrotation of FPA unlike AFO. Overall, TC alone demonstrates effective correction in the in-toeing or out-toeing gait in children with NMD.

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DISCLOSURE STATEMENT

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Internal hip rotation and swing phase knee flexion in typical adolescent gait: A case-control pilot study

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INTRODUCTION

Stiff knee gait (SKG) is a common gait deviation in patients with cerebral palsy (CP) and can significantly impact walking function. SKG is often treated surgically with a distal rectus femoris transfer (RFT). Indications for this surgery are varied [1]. Among these, a common indicator (prolonged rectus femoris muscle activity in swing) has shown somewhat mixed results as a positive indicator for RFT [e.g., 2, 3]. In addition, previous research has documented mixed outcomes from RFT surgery which may be due to patient selection [4].

It may be that other factors are important to SKG. Internal rotation of the hip secondary to increased femoral anteversion is one potentially significant but understudied concomitant gait deviation. This impairment creates an oblique orientation of the knee rotation axis relative to the path of progression, which may interfere with the typical passive knee flexion mechanism during gait. The purpose of this pilot study was to assess the relationship between average hip rotation in early swing and peak knee flexion in swing in two age-matched adolescent girls, one with idiopathic increased femoral anteversion and one without.

CLINICAL SIGNIFICANCE

Outcomes following treatment for SKG in children with CP depends on understanding all the contributing factors to this gait deviation to improve patient selection.

METHODS

The study protocol was reviewed and approved by the Institutional Review Board at Grand Valley State University. Two adolescent girls, one with increased femoral anteversion bilaterally (KE) and one without (JL) were invited to participate. With parent consent and child assent, data were collected in the Biomechanics and Motor Performance Laboratory at GVSU (16 Vicon cameras, Nexus 2.14 software). The lower extremity Plug-In Gait model was used with standard marker placement and protocol. A total of 15 trials were collected for each participant. For each trial, two gait cycles from each limb were identified (30 total gait cycles). Final data reduction was completed in Vicon's ProCalc software to extract peak knee flexion in swing (PKFsw) and calculate average hip rotation (AvgHipRot) between toe-off and peak knee flexion for each gait cycle. Data for each measure were analyzed with a two-way (person x leg) repeated measures ANOVA.

RESULTS

Per physician records, KE presented with excess femoral anteversion and bilateral hip rotation profile of 70°/30° (external/internal). Figure 1 illustrates the average left and right joint angles for KE compared to the bilateral average of JL (grey band). The ANOVA revealed that KE walked with significantly increased internal hip rotation in early swing on the right and left compared to JL, and significantly lower peak knee flexion in swing bilaterally compared to the JL (Table 1). A leg*person interaction effect was also found for both measures (PKFsw, p <0.011 and AvgHipRot, p<0.0001).

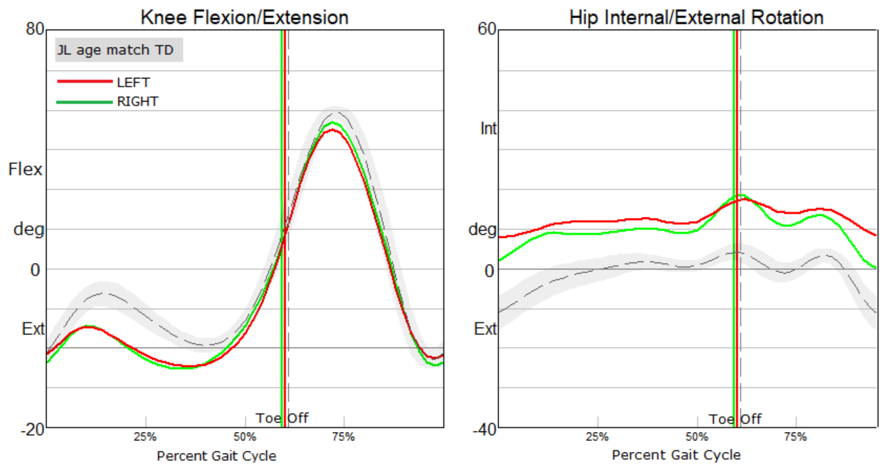

Figure 1. Average knee flexion and hip rotation for KE (L red, R green) and JL (grey band is mean ± 1sd).

Table 1: Mean (sd) for each measure for each participant and leg.

	L PKFsw*, +	RPKFsw (deg)*, +	L AvgHipRot (deg)*, #	R AvgHipRot (deg)*, #
JL	60.7 (0.6)	60.4 (0.6)	-0.8 (0.8)	3.1 (0.8)
KE	57.3 (1.6)	55.7 (1.2)	15.3 (0.5)	16.3 (0.5)

*p<0.0001, leg*person interaction +p<0.011, #p<0.0001

DISCUSSION

The results of this pilot study indicate that there may be a meaningful inverse relationship between internal hip rotation during early swing and the magnitude of peak knee flexion achieved during swing. In this pilot study of two participants, the finding of a significant leg*person interaction effect is likely spurious. We expect that this interaction would be non-significant in a study with a larger N. In addition to increasing sample size, including a larger range of femoral anteversion and hip rotation profiles would give clinicians better information about the relationship between these two measures. Additional insights could be obtained if surgery were undertaken to treat the femoral anteversion in those individuals, and peak knee flexion was found to be increased post-operatively.

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DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.