Influence of Cardan Sequences on Ankle and Hindfoot Kinematics

Anthony H. Le[1,2], Andrew C. Peterson[1], Kassidy Knutson[1,3], Bruce A. MacWilliams[1,4], Karen M. Kruger[5,6], Amy L. Lenz[1,3]
Department of [1]Orthopaedics, [2]Biomedical Engineering, [3]Mechanical Engineering, University of Utah, Salt Lake City, UT, USA
[4]Motion Analysis Center, Shriners Hospital for Children – Salt Lake City, Salt Lake City, UT, USA
[5]Department of Biomedical Engineering, Marquette University, Milwaukee, WI, USA
[6]Motion Analysis Center, Shriners Hospital for Children – Chicago, Chicago, IL, USA
Email: anthony.le@utah.edu

Summary

This study assessed how each Cardan sequence influences ankle and hindfoot kinematics in gait analysis and cadaveric passive range of motion testing. Significant differences between sequences were largely observed in the subtalar and talonavicular joints across all 3 motion planes. Results demonstrate that sequence choice impacts biomechanical interpretations, emphasizing its importance for clinically relevant joint function analysis.

Introduction

Three-dimensional ankle and hindfoot joint kinematics are calculated using the Euler/Cardan method, but choice of Cardan sequence affects interpretability. While XYZ (X: medial-lateral, Y: posterior-anterior, Z: inferior-superior) is recommended [1], this sequence may not always be suitable for analyzing coronal and transverse plane angles [2]. This study examined the impact of all 6 Cardan sequences (XYZ, XZY, YXZ, YZX, ZXY, and ZYX) on ankle and hindfoot kinematics across all 3 motion planes using gait analysis and cadaveric passive range of motion (ROM) testing.

Methods

For gait kinematics, 7 healthy young adults participated in biplane fluoroscopy gait analysis at a self-selected speed. For passive kinematics, 5 tibia-to-toes cadaveric specimens with motion capture markers in bones were loaded to 25% body weight in a neutral pose and prescribed tibial dorsi-/plantarflexion, external/internal rotation, and varus/valgus alignment (VR/VG) to end ranges. Weightbearing CT scans determined bone local coordinate system transformations for bone-level tracking. SPM analyses compared tibiotalar, talofibular, tibiofibular, subtalar (ST), and talonavicular (TN) joint rotations across all 6 Cardan sequences ($\alpha = 0.05$).

Results and Discussion

Significant kinematic differences between XYZ and other sequences were largely observed in the ST and TN joints during stance phase of gait (**Figure 1A**) and prescribed tibial VR/VG (**Figure 1B**). During stance phase of gait, YZX, ZXY, and ZYX increased ST eversion and TN inversion, while YZX increased TN external rotation. During prescribed tibial VR/VG, XZY, ZXY, and ZYX amplified sagittal ST kinematics, while YZX, ZXY, and ZYX reduced coronal ST, but amplified transverse ST kinematics. XZY, ZXY, and ZYX reflected sagittal TN kinematics, while XZY, YXZ, YZX, ZXY, and ZYX amplified coronal TN kinematics, and YXZ, YZX, and ZYX reduced transverse TN kinematics.

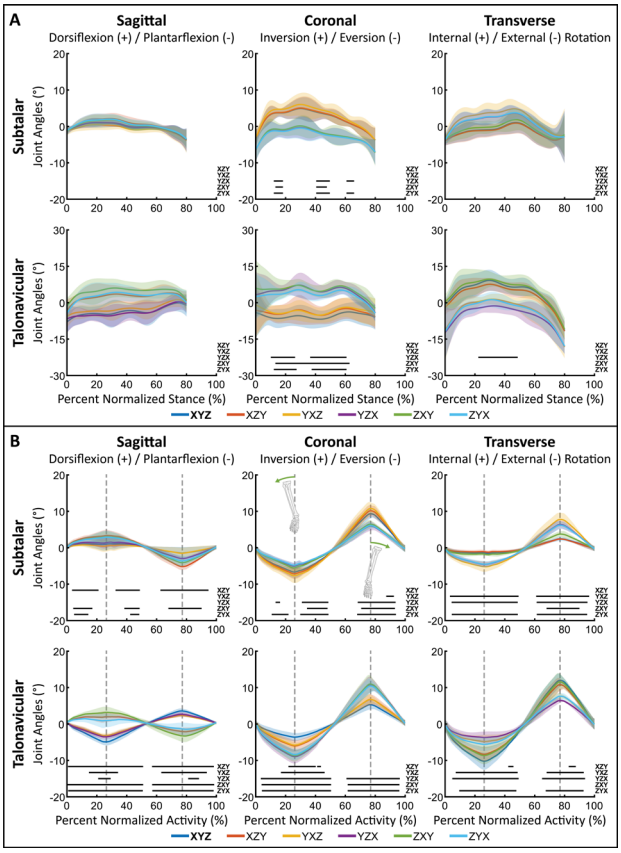

Figure 1: Mean (±SD) ST and TN kinematics during (**A**) gait and (**B**) prescribed varus/valgus for all 6 Cardan sequences. Black bars indicate significant differences between XYZ and other sequences. Grey dashed lines indicate peak prescribed varus and valgus.

Conclusions

Cardan sequences significantly influence ankle and hindfoot kinematics, especially in the ST and TN joints. Based on how kinematics are amplified or reduced in specific planes, XYZ, XZY, or YXZ are recommended for the ST joint, while YZX or ZYX are recommended for the TN joint. Our findings emphasize the importance of sequence selection in kinematic analysis to ensure appropriate and consistent biomechanical and clinical interpretations of individual joint function.

Acknowledgments

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References

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