Measuring Fibular Kinematics with Marker-Driven Models in OpenSim

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Summary

Previous work reporting normative fibular motion during gait is limited, and studies do not agree on the primary direction of motion. This study evaluates marker-driven models to track the fibula during gait. Measured kinematics agree well with previously reported magnitudes of motion. But, future work is needed to characterize time-series gait mechanics and investigate how differences in subjects and/or experimental methods influence kinematic variability.

Introduction

Humans comprise one of only two orders in the Animal Kingdom with fully-mobile fibulae [1], suggesting a unique biomechanical role. Yet, normative fibular kinematics are not well understood. Only three studies report fibula range of motion (ROM) *in vivo* during gait, and they examined only the stance phase [2-4]. These studies agree the fibula moves several degrees, but they disagree on distribution of motion across planes. Studying the fibula is challenging: existing techniques are either invasive (bone pins) or resource-demanding (biplane fluoroscopy). The objective of this study was to characterize fibular kinematics during gait using a novel marker-driven modelling approach.

Methods

Ten healthy subjects (5 female; 23±3 years; 69.7±15.6 kg; 1.7±0.1 m) participated in this IRB-approved study. Helen Hayes lower limb and Rizzoli multi-segment foot marker sets were placed on each subject; with markers added to proximal, mid-shaft, and distal fibula landmarks (72 total markers; 3 on each fibula). Motion capture data were collected at 200 Hz during 9 tasks with a 30-camera Motion Analysis system. Here, results from overground barefoot walking are analyzed.

A mobile fibula model was developed using OpenSim 4.0 by augmenting the Rajagopal [5] model with a six-degree-of-freedom distal tibiofibular joint. This joint defined fibula motion relative to the tibia. Models were scaled to represent subjects using AddBiomechanics [6]. Inverse kinematics simulations were run for each trial of filtered marker data in OpenSim 4.5. Fibula ROM was extracted from filtered, time-series kinematic data for comparison to reference values [2-4]. ROM was averaged across stride, trial, subject, and leg.

Results and Discussion

Kinematic results indicate that the fibula primarily extends and abducts during walking (Fig. 1), but rotates both internally and externally. This finding agrees with previous research evaluating simulated gait in cadavers [7], which found that ankle dorsiflexion induces external rotation of the fibula, while ankle plantarflexion induces internal rotation of the fibula. Interestingly, ROM limits occurred during the end of stance, which involve changes in limb loading as the limb transitions to swing.

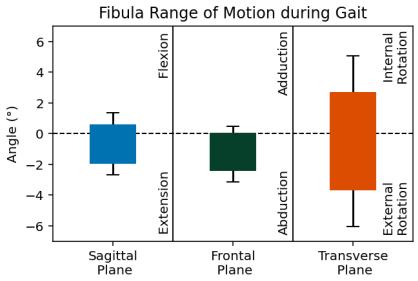

Figure 1: Fibula range of motion in each plane during full gait cycles (stance and swing). Error bars represent standard deviation.

The fibula ROM measured herein is the same order of magnitude as prior studies (Table 1). However, our results show highest ROM in the transverse plane, unlike Lundgren et al. [2] and Pitcairn et al. [4], which show highest ROM in sagittal and frontal planes, respectively. Differences likely arise due to methodology; definition of fibula origin and angle decomposition order vary across studies. Prior work also only report data during stance, which may not capture effects observed in transition from stance to swing. Inter-subject differences may also contribute to variability. Initial time-series analyses suggest distinct patterns of motion across subjects, potentially from variations in fibular morphology.

Table 1: Literature Comparisons of Fibular ROM (mean ± st. dev.)

	Bone Pins[2]	Biplane Fluoroscopy[3,4]		This Study
Sagittal	4.8° ± 1.7°	3.0° ± 1.1°	4.0° ± 1.7°	2.5° ± 0.8°
Frontal	3.4° ± 1.3°	6.0° ± 1.5°	9.0° ± 2.2°	2.1° ± 0.8°
Transverse	3.6° ± 1.3°	6.0° ± 2.0°	3.4° ± 1.0°	6.3° ± 2.4°

Conclusions

This study suggests that our novel marker-driven modeling method can be leveraged to measure fibular motion, thereby expanding the accessibility of studying fibular biomechanics.

Acknowledgments

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References

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