Development and Validation of Machine Learning Algorithm to Predict Foot/Ankle Gait Kinetics and Kinematics using Anthropometric Parameters

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INTRODUCTION: When performing in vitro orthopedic biomechanics foot/ankle research, selection of the motions and loads driving the robotic testing simulator are important elements of the study design. Normalizing the ground reaction forces (GRF) by body weight is a commonly accepted way to use in vivo gait data and apply it to in vitro testing specimens [1, 2]. However, there is currently no widely accepted solution to normalize gait kinematics and scale by anthropometric parameters such as foot length and foot width, or other parameters that might be predictive. In addition, the linear scaling normalization of GRF by body weight may not adequately capture the differences between subjects of different mass or height. The aim of this study was to predict gait kinetics and kinematics based on foot/subject anthropometric data for robotic in vitro biomechanical testing of feet.

METHODS: We collected 6-degrees-of-freedom (6-DOF) stance phase tibia kinematics and GRF for 30 individuals (16F, 14M) (56±8 years) that were either normal subjects (n=20) or flatfoot subjects (n=10). We also collected demographic (sex and age) and anthropometric (height, mass, overall foot length, first to fifth metatarsal width, intermalleolar width, intercondylar width, medial malleolus height, lateral malleolus height, arch height, and heel to first metatarsophalangeal joint) data. A system for transforming translation, rotation, and GRF time series graphs into a lower dimensional latent dataset using feature extraction and graph-weighted principal component analysis (PCA) was developed. A primary unsupervised learning algorithm converted the latent data into force and motion profile classifications (bins). A secondary decision model was created to classify associated anthropometric cadaveric data into a bin with a defined force and motion profile.

RESULTS SECTION: The optimal (most accurate) number of bins the binning algorithm selected, per the elbow and silhouette method, was determined to be 4 (silhouette score of 0.24). Using clustering, each individual's mean trial is sorted into a specific bin (Figure 1). The decision tree was found to be 83% accurate with a maximum of 4 questions (Figure 2).

DISCUSSION: This study demonstrates the feasibility of predicting foot/ankle gait kinetics and kinematics using anthropometric parameters, providing a novel approach to scaling biomechanical data beyond traditional normalization methods like body weight. The developed machine learning model achieved an 83% accuracy in classifying gait profiles, highlighting its potential utility for robotic in vitro testing and specimen specific biomechanics research. While the current focus is on in vitro applications, expanding the dataset could enable broader applications in in vivo and in silico studies.

SIGNIFICANCE/CLINICAL RELEVANCE: This is the first study, to our knowledge, of predicting a classification of foot/ankle gait kinetics and kinematics using anthropometric parameters. These findings provide a roadmap for more precise and individualized approaches in foot/ankle biomechanics research.

REFERENCES: 1) Noble et al. J Biomech Eng. 2010, 2) Aubin et al. IEEE Trans. on Robotics. 2012

IMAGES AND TABLES:

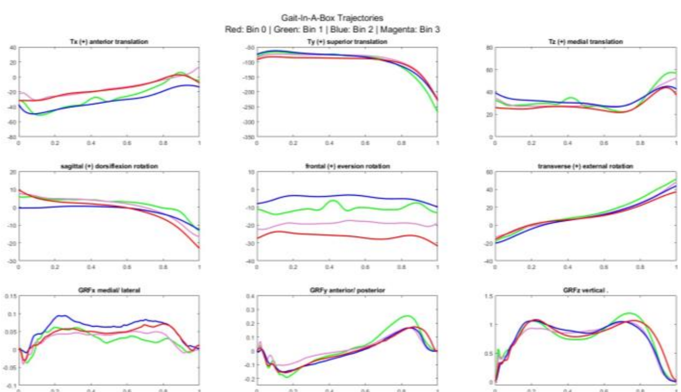

Figure 1: Median motion and load profiles for each bin

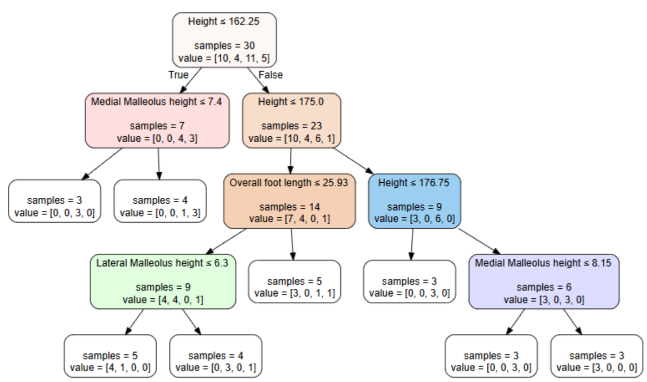

Figure 2: Decision tree using anthropometric data to select proper profile