

CADAVERIC GAIT SIMULATION

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INTRODUCTION

The relationship between foot structure and foot function has received much recent study. Often, static cadaveric models are employed. However the relationship between dynamic bony alignment and plantar pressure during gait is not well understood. To further investigate the relationship between foot structure and foot function, we are developing a Cadaveric Gait Simulator (CGS), capable of generating neutrally aligned and pathologic foot kinematics, kinetics, ground reaction forces (GRFs) and plantar pressures. The CGS will be used to generate pathologic pre- and post-surgical gait simulations, as well as conservative treatment simulations. This will serve as a tool for clinicians to explore more efficacious treatment strategies for patients with pathological feet.

Existing dynamic, cadaveric gait simulators are potentially limited by the following: scaled gait simulation speeds, simplified rigid body motion of the tibia, or scaled GRFs (Kim *et al.*, 2001; Hurschler *et al.*, 2003; Ward *et al.*, 2003; Hamel *et al.*, 2004). To overcome these challenges, a novel six degree of freedom parallel link hexapod robot (R-2000, Parallel Robotic System, Inc; Hampton, NH) was used (Figure 1).

Our future work will use cadaveric limbs, but to date we have only employed a prosthetic foot and pylon as an initial step.

METHODS

The prosthetic limb was mounted to a rigid frame that is mechanically grounded to the floor while the robot simulated the motion of the “ground” relative to the limb. Thus the pylon (or tibia) was stationary while the “ground” was moved by the robot to accurately reproduce the relative pylon - ground rigid body motion. In the future, nine linear actuators will supply force via tendon clamps to the extrinsic muscle tendons of the foot.

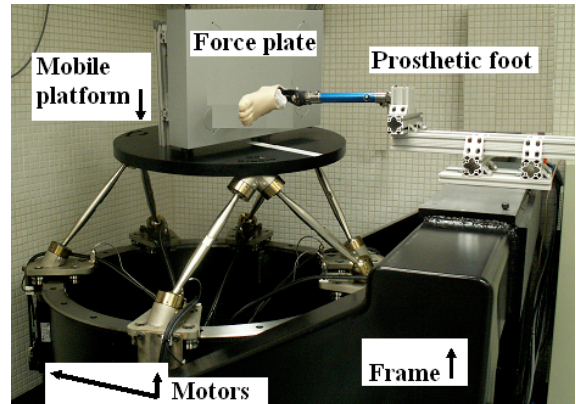


Figure 1: The Cadaveric Gait Simulator.

The rotational rigid body motion of the tibia with respect to the ground will be recorded from living subjects (normal and pathologic) with a Vicon twelve camera retro-reflective motion analysis system. To date, we have collected gait data from one transtibial amputee. The robotic “ground” was constrained to recreate the sagittal, coronal, and transverse plane rotations of the *in situ* prosthetic limb. The three translations of the robotic “ground” were adjusted between gait simulations using a proportional iterative

learning controller in order to reproduce the recorded *in situ* GRFs. Changes to the “ground” trajectory were limited to incremental displacements along the vertical ground axis. This ensures that the simulated rotational kinematics of the tibia matched the recorded *in situ* gait data while also achieving the target GRFs. The motion of the prosthetic foot was not directly constrained but rather a function of the “ground” kinematics and kinetics, GRFs, and, in the future, tendon forces.

During the simulation, a force plate attached to the robot measured the GRFs. In the future, a Peak six-camera retro-reflective motion analysis system will measure the rotation of eight bones (the calcaneus, talus, navicular, cuboid, medial cuneiform, and 1st and 5th metatarsals) via bone pins and marker triads. Further, a plantar pressure measurement device will be mounted in series with the force plate.

RESULTS AND DISCUSSION

Simulating transtibial prosthetic gait has been the first step to implementing the Cadaveric Gait Simulator. To date, pylon kinematics and GRFs (scaled to 3 seconds and approximately 50% body weight) were simulated and compared to *in situ* gait data (Figure 2). The scaled vertical GRF during the stance phase of transtibial prosthetic gait had an RMS error of 14 N between the *in situ* and simulated gait. The iterative learning controller took 14 gait iterations to reduce the RMS error from 232 N to 14 N. Further improvements to the RMS error require an increased force plate signal to noise ratio as well as compensation for the inertial effects of the moving force plate.

The R-2000’s typical positional error is only 50 μm , meaning the “ground” kinematics will have insignificant amounts of error.

Thus the simulated versus *in situ* “ground” kinematics are identical except for errors due to data collection noise and foot mounting inaccuracies. The data collection noise was estimated to be on the order of a few degrees and a misaligned prosthetic foot only shifts the simulated rotational kinematic curves but accurately maintains their range of motion and rate of change.

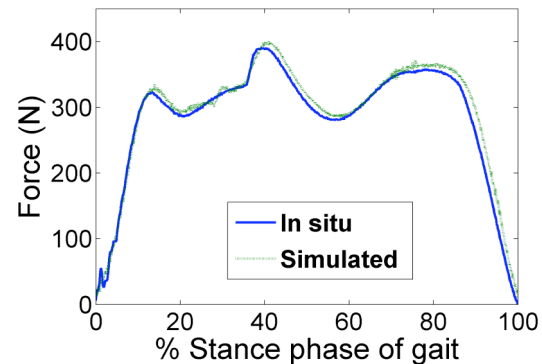


Figure 2: *In situ* and simulated vertical GRF.

Future work includes increasing forces to 100% body weight and decreasing the simulated time of stance phase to 0.75 sec by optimizing the “ground” trajectory within the working volume of the R-2000. Cadaveric simulations with active “muscle” forces will follow.

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