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How Do We Accurately Measure Foot Motion?

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Understanding foot motion is pivotal to understanding lower extremity mechanics during gait. Variations in both foot structure and foot mechanics greatly influence motion of the more proximal segments of the lower extremity. The potential for this variation is great. The foot is an incredibly complex structure comprised of 26 or more bones and over 30 articulations, each with 6 degrees of freedom of movement. While these facts have been appreciated for a very long time, until recently, biomechanists have been treating the foot as a single rigid body. This is due, in part, to past limitations of motion analysis systems. The resolution of earlier systems did not allow tracking of multiple markers on the foot. While current motion analysis systems are now capable of much greater resolution, foot marker placement for some popular marker sets prohibits accurate measurement of foot frontal plane motion. However, frontal plane motion is considered a very important functional component of foot mechanics.

With improvements in resolution, other foot models have emerged that permit the measurement of the full 6 degrees of freedom of motion of the rearfoot. However, as markers are placed on the calcaneus and tibia, the motion being measured is a summation of talocrural and subtalar joint motion. One often interprets the resulting data as the sagittal plane motion occurring at the talocrural joint, and the frontal and transverse plane motion occurring at the subtalar joint. However, this interpretation is not without limitation, as we know that both joints have 6 degree of freedom movement. While these models have provided information regarding rearfoot motion, motion of the midfoot has remained an enigma.

There has been much suggestion in the literature of the importance of the midfoot in foot function. For example, studies of the effect of foot orthoses on rearfoot motion have added little insight into the reason for the efficacy of this intervention. It is very possible that the orthotic effect on the midfoot may be much more important than that of the rearfoot. However, the motion of the midfoot is extremely difficult to accurately measure with standard motion analysis techniques. To measure 6 degree of freedom of motion, at least 3 noncollinear markers on each bone of interest are needed. Even if the resolution of the measuring system allows this, having room to place 3 markers on a single bone becomes an issue. This had led researchers to group bones together to form functional segments of the foot. Therefore, markers are placed on separate bones, which are assumed to form rigid segments. However, the validity of these models depends on the degree to which this assumption is true.

New techniques show promise with respect to gaining insight into foot motion. Cadaveric studies have allowed the measurement of movement of the individual bones of the foot through the use of bone markers. While these data cannot be directly extrapolated to in vivo mechanics, recent advances in gait simulators have brought us one step closer. These systems allow the introduction of appropriately timed and scaled muscle forces, such that the kinematics and kinetics of gait are quite realistic. In addition to these advances, imaging techniques, such as MRI, have provided patient-specific data to improve upon foot models

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that are currently being developed. In addition, dynamic imaging techniques, such as fast-PC MRI are emerging and allowing the in vivo measurement of individual bone motion not possible with standard motion analysis techniques.

The aim of the second Foot and Ankle Research Retreat was to address the issues related to the measurement of foot motion. It was sponsored by the Foot and Ankle Special Interest Group and the Orthopaedic Section of the APTA, along with the Department of Biokinesiology and Physical Therapy at the University of Southern California, and was held this past spring. A variety of different foot models were presented. Issues related to reliability and validity were discussed. New techniques, including the use of gait simulators and fast-PC MRI imaging, were presented. The description of this retreat, along with the abstracts of the presentations and the consensus statement from the participants are included in this issue. It is hoped that, as those interested in measuring foot motion read through these abstracts and the consensus statement, ideas for future research will be generated.

Following this retreat, it was clear to all of us that we must continue our dedication to the development of ways of measuring the true movement complexities of the human foot.