FOOT/ANKLE KINEMATICS: COMPARATIVE ANALYSIS OF NORMAL FOOT VS. FLAT FOOT DEFORMITY

Rita M. Patterson, Ph.D., Dr. Saul G. Trevino, M.D., Dr. Anthony J. Wright, M.D., Takayuki Nakamura, M.S., Tony Longo, and William L. Buford, Ph.D.

Department of Orthopaedics and Rehabilitation
Orthopaedic Biomechanics Laboratory
The University of Texas Medical Branch at Galveston
Galveston, Texas

INTRODUCTION:

With an aging population, there is an increased emphasis on walking and other physical activities to maintain cardiovascular and musculoskeletal fitness. Recent advancements in Orthopaedic surgery have recognized that an acquired flat foot can be disabling, requiring bracing or surgical reconstruction. This study will use real time video motion analysis to investigate kinematics of the normal foot/ankle complex and with a simulated flat foot deformity. Kinematic analysis of normal and abnormal motion will add improved objective measures for evaluating surgical treatments for foot instabilities. It will assist physicians with treatment choices and lay the foundation for future studies investigating/evaluating other injuries in the foot and ankle.

The flatfoot deformity increases foot/ankle range-of-motion and causes distraction and compression of various joints therefore altering normal foot/ankle biomechanics and kinematics.

MATERIALS/METHODS:

Four fresh frozen cadaver lower extremities free from visible or radiographically identifiable deformities and/or degenerative changes were be studied. Triad pins are placed percutaneously into the tibia, fibula, talus, calcaneus, navicular, cuboid, all three cunieforms, and all five metatarsals. Each triad pin has three orthogonal, 3mm diameter spheres that that are used as targets for tracking. The spheres are coated with 3M photo-reflective paint to enhance their reflectance to video cameras. The pins are placed into the bones with fluoroscopic guidance (FluoroScan Imaging Systems, Inc., Northbrook, IL), carefully making sure that they will not come into contact with each other during a full passive dorsi/plantar flexion range of motion of the foot. The pins are designed and placed to assure that they are rigidly attached to the bones and will not flex or vibrate independently. Care is taken not to place the pins through tendons or other soft tissue that is involved in ankle motion so as to prevent, alter or otherwise influence motion. The lower extremity is placed in a jig that stabilizes the tibia and allows free motion of the foot and ankle. The tibia is mounted vertically and the posterior tibialis, anterior tibialis, peroneals and Achilles tendon loaded with 1 lb. weights. The weights are applied to sutures attached to the muscle insertion sites and will simulate normal muscle tonus. Video motion analysis (VMA), a method of recording the 3D spatial motion of joints using optical sensors, is performed on the cadaver specimens during foot/ankle dorsiflexion/plantarflexion, inversion/eversion, and supination/ pronation at a rate of 60 frames per second. VMA is performed prior to sectioning any ligaments (normal condition) and repeated after the superomedial spring ligament, plantar ligament, interosseous ligament, superficial deltoid ligament, deep deltoid ligament, and long plantar ligament are disrupted (simulating a rigid flatfoot). EVA (Motion Analysis Corp. Santa Rosa, CA), a tracking program, creates 3D coordinate files for each target identified by processing data from each of the cameras. The resultant "raw" 3D file is checked for errors using the tracking editor program. The resulting files contain the x, y, and z coordinates for each of the three targets on the pin for each frame of data acquisition.

After the motion analysis data has been recorded, transverse images of the foot and triad pins are obtained with a GE 9800 CT scanner (General Electric, Milwaukee, WI) generating contiguous slices 1.5 mm thick. The CT images are processed using Mimics (Materialise, *nv*, Ann Arbor, MI) in order to create a 3D computer model of the foot. Data from the Motion Analysis System is combined with the information from the CT scans to create an animation of the motion of the bones as well as to calculate several measurements that are hypothesized to characterize tarsal bone motion in the normal foot. The relationship between the pin and bone coordinate system is determined using the center of gravity of each object. Center of gravity information for each imaged tarsal bone and its respective triad pin spheres will be calculated from the CT reconstructions. The path data from the Motion Analysis system is extracted and related to the CT coordinate system. The relationship between the moving triad pin coordinate system and the fixed pin coordinate system is then computed. The resultant file contains the six-degree-of-freedom orientation and displacement information necessary to describe the position of the designated moving bone body in relation to the fixed bone.

For the normal foot/ankle and flatfoot models, the output of the kinematic acquisition data is then used to reconstruct a frame-by-frame movement of the imaged CT scan data as measured by the video motion analysis system. This frame-by-frame motion is displayed in AVS on the Evans and Sutherland graphics computer workstation. Once the animation of each tarsal bone with respect to the tibia is visually satisfactory, when compared with 2D Flouroscopic images, the files are merged and an animation of the motion is created.

Once the animations are satisfactory, measurements between any two bones in the foot/ankle complex can be calculated. Measurements obtained are total range of motion (ROM) and angles between bones. Total range of motion information gives insight into the functional range of motion and the ability of the extremity to perform normal, or even basic, functions of daily living. Angles between bones are calculated to give insight into the way the tarsal bones articulate.

RESULTS:

Range-of-motion (ROM), angles between bones, in both a normal and flat foot are calculated. Graphs 1, 2, and 3 show the average range of motion in each of the body planes for all bones in the foot/ankle complex relative to the tibia. Table 1 shows the difference in degrees between the normal range of motion and the flat foot range of motion in each of the body planes for all bones in the foot/ankle complex relative to the tibia.

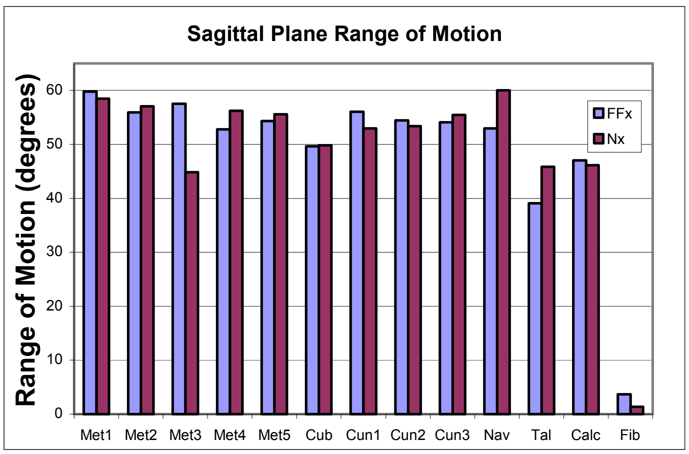

Figure 1 FF= flatfoot condition, N= Normal condition

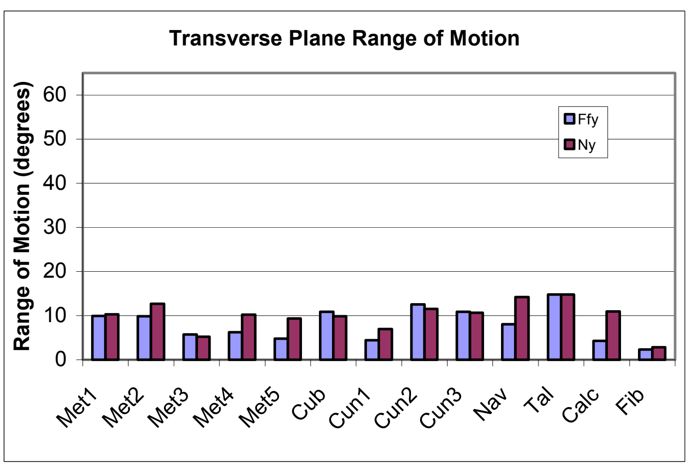

Figure 2 FF= Flatfoot condition, N= Normal Condition

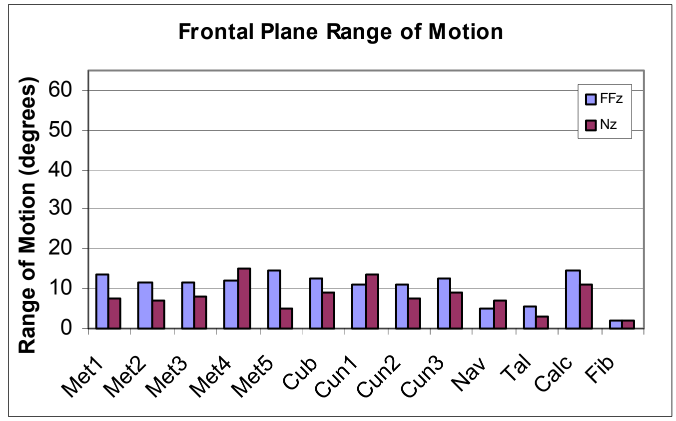

Figure 3 FF= Flatfoot Condition, N= Normal Condition

Tibia vs	Sagittal	Transverse	Frontal
Met1	54.80	7.97	5.82
Met2	-12.22	-7.47	0.57
Met3	-0.63	-0.83	-10.43
Met4	3.12	-2.88	4.35
Met5	2.03	-0.91	1.37
Cub	-4.70	0.50	0.50
Cun1	-4.68	6.10	-2.24
Cun2	-1.62	8.17	0.13
Cun3	-1.15	-2.82	-7.63
Nav	-14.15	0.60	-4.32
Tal	-44.77	-8.17	-9.10
Calc	-3.87	-0.10	-1.93
Fib	7.93	-10.53	8.98

CONCLUSIONS/SIGNIFICANCE:

Total range-of-motion information gives insight into the functional range of motion and the ability of the extremity to perform normal, or even basic, functions of daily living. Angles between bones are calculated to give insight into the way the tarsal bones articulate. Using these measurements, the malalignment indicative of instability can be displayed and further correlated to measures on two-dimensional x-rays. This will possibly lead to the ability to detect the abnormality at an earlier stage in the time-line of the pathology.

Acknowledgements:

This study is funded by the American Foot and Ankle Society