C-arm Fluoroscopy:
Developing a Method for Orthotic Analysis

Medical Biophysics 3970Z
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Introduction

The use of foot orthotics are becoming more prevalent in today’s society. From foot ailment sufferers to elite athletes, people are seeking these custom made devices as solutions to foot, ankle, knee, and back pain. Unfortunately the orthotic industry is highly unregulated. The decisions which surround the specific orthotic design for an individual are largely dependent on the orthotist’s personal experience and preference. This methodology is adequate as long as the custom made device is positively received by the patient. However, when orthotics fail to address the desired need, how is the orthotist to know the reason why—especially during dynamic motion?

This research will attempt to develop an accurate method for orthotic analysis. Currently the most common method for conducting a three-dimensional (3D) analysis is by using a camera-based optical tracking system. This technique utilizes reflective markers placed on the skin to track kinematic movement and therefore is known to produce errors due to skin motion and the differences between the tracked soft tissue properties instead of this bone (Kedgley et al. 2009). By using the novel method of combining 3D fluoroscopic radiosteriometric analysis (fRSA), computed topography (CT), and modelling software, an accurate 3D model of a patient’s foot during motion can be created. It is hoped that this model will allow for endless analysing capabilities and be directly applicable to the orthotic industry.

For this experiment, 21 patients will be divided equally into three categories; flat foot, normal, and high arch. Each patient will be fitted with four pairs of custom made orthotics, a result of combining the common techniques of creating an orthotic mold; proctor casting and fox box, as well as two of the common types of orthotics; rigid and soft. Due to the restrictive time of this project, a preliminary two dimensional analysis will be completed by measuring the calcaneal-first metatarsal angle (C1MA) from a lateral perspective.
Theory

For this experiment, two orthotic types; rigid and soft, and two molding techniques; plaster casting and foam box, will be demonstrated. In order to develop the method for orthotic analysis, a 3D model in real time motion will be created using C-arm fluoroscopic radiosteriometric analysis (fRSA), a CT image, and the modelling software Rhinoceros.

There are currently two main types of orthotics being made, rigid and soft orthotics. Rigid orthotics are preferred by flat footed (pen planus) individuals. They provide the support and stability these individuals require and prevent the tendency of overpronation, rolling of the ankle inward during gait. Soft orthotics are preferred by high arched (pes cavus). They prevent oversupination, describing the outwards roll of the ankle outwards during a walking motion. Soft orthotics feature cushioning, balance, and shock absorption that a high arched individual seeks though has a shorter life expectancy compared to a rigid model.

There are also two current methods in the orthotics industry for creating the mold for a pair of custom made orthotics, plaster casting and foam box. Plaster casting is perceived my some orthotists as the leading technique. A patient lies face down while leaning their foot to be molded on the opposing calf. The orthotist then holds the foot in the subtalar joint in neutral position (ideal foot position) and applies a plaster slipper. After hardening, the slipper is carefully removed. The foam box method of molding has a patient step into a slab of foam while standing. This method is quick, clean, and less expensive than plaster casting. Certain orthotists prefer this method as it allows for natural soft tissue deformation and the accommodation of any extra support devices (ankle braces) that may be worn with the orthotics.

C-arm fluoroscopy is a live X-ray imaging technique. An image intensifier is used to amplify low intensity X-rays which allow a patient to be exposed to less radiation. A CCD camera is coupled to the image intensifier which will enable the feed to be displayed on a monitor. C-arm fluoroscopy allows for
the recording of all activity which will provide accessible future analysis. Last image hold is also a feature that will be utilized which halts the radiation exposure while displaying a still image of the last frame. In this experiment two C-arm fluoroscopes will be used simultaneously to yield the two image planes as required for radiosteriometric analysis. Before a patient’s foot is capture by the fluoroscopes, a still image of a calibration box will be taken. The calibration box, designed by Kedgley (2009) has different sized titanium beads placed in known precise locations. Having the calibration box imaged from both fluoroscopes defines x,y,& z planes and allows for the determination of the location of both fluoroscopes relative to each other. This enables images to be correctly calibrated using a calibration code created by Allen (2009) using MATLAB.

Radiosteriometric Analysis (RSA) is the process of creating a 3D model from two bi-planar fluoroscopic images if their position relative to each other is known. Frames of interest will be digitized using Adobe Photoshop and patients will also be sent for a 3D CT scan. Both the fluoroscopic images and the 3D CT scan will be imported into the modelling software Rhinoceros. The process of bone matching will be used to match the CT image in each frame to the corresponding position on the fluoroscopic image.

Due to the time constraints of this project, a preliminary two-dimensional (2D) arch analysis will be performed using the calcaneal-first metatarsal angle (C1MA) and the lateral images resulting from fluoroscope A (Menz et al.2008). This will be completed using the imaging tool box in MATLAB. It is estimated that as more support is added to the foot the C1MA will decrease.

Methods

This experiment was completed at the Wolf Orthopaedic Quantitative Imaging Laboratory (WOQIL) at the Fowler Kennedy Sports Medicine Clinic in London, Ontario. All work was conducted
under the supervision of Dr. T. Jenkyn, Director of the WOQIL, and Master’s candidates; Megan Baldson and Kristen Bushey.

The subject group included 21 patients, divided into three subcategories each containing seven patients. The three subcategories contained patients diagnosed by the in clinic orthotist as having flat, normal, and high arches.

First a wooden platform was constructed to be level with fluoroscope A positioned at 180° horizontal. Fluoroscope A will yield a lateral view of the patient’s left foot. Fluoroscope B was positioned to yield an anterior and slightly oblique view of the foot. Refer to figure 1 for the complete experimental design.

Prior to arrival for the experiment, all patients were fitted with four pairs of custom made orthotics. Each pair featured one orthotic type (rigid or soft) combined with one of the two molding techniques (plaster casting or foam box). After the orthotics had been created and fitted, each patient was recorded as they walked normally between the two fluoroscopes. Note the fluoroscopes are positioned to only capture the left foot. The patient was to complete six gait trials, one; barefoot, in a
neutral shoe, and in each of the four orthotics. Each orthotic was placed in the same neutral shoe which was kept consistent amongst all participants (only varying in shoe size). Before the patient began the trials a still image of the calibration box was taken. The fluoroscopes were then each controlled by foot pedals and pressed simultaneously by the X-ray technician to begin recording at the same time. To correct for any time discrepancies in the post imaging analysis a string was taped to the face of each fluoroscope and pulled simultaneously to serve as a reference time stamp for future syncing.

Once all the recordings were collected, the analysis could be performed. Specific frames of interest would be selected and digitized in Adobe Photoshop and calibrated against the calibration box correct code in MATLAB designed by Kedgley et al. (2009. Each patient was then sent for a 3D CT scan of their left foot. Both digitized fluoroscope images (from fluoroscopes A and B) and the CT image could then be imported into the modelling software Rhinoceros. Using the technique of bone matching, the CT scan was matched to both fluoroscope images and a through radiosteriometric analysis a 3D model of the foot as it progresses through normal gait during in-vivo motion could be developed.

Note: At the beginning of this six week project, the graduate students were too at the beginning of their thesis and never reached the point of the 3D analysis. Therefore a preliminary 2D analysis which calculated the calcaneal-first metatarsal angle (C1MA) was performed using the images captures by camera A (lateral view) as the entire sole of the foot made contact with the surface. This measurement was completed using the MATLAB imaging toolbox (refer to figure 2).
Results

At the completion of this six week project two patients from the normal arch subcategory had been imaged. Of the two patients, one resulted in partially usable data and neither patient had yet to be CT scanned.

<table>
<thead>
<tr>
<th>Patient ID: 6F</th>
<th>(C1MA) (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>barefoot</td>
<td>121.66</td>
</tr>
<tr>
<td>neutral shoe</td>
<td>115.96</td>
</tr>
<tr>
<td>soft plaster cast orthotic</td>
<td>113.65</td>
</tr>
<tr>
<td>rigid plaster cast orthotic</td>
<td>112.22</td>
</tr>
</tbody>
</table>

Figure 3. Useable data from patient 6F.

The figure above shows four gait trials from which some C1MA’s were able to be measured. Missing from the data due to image obscurities are the two trials containing soft and rigid foam box orthotics. The C1MA decreases as expected as more support is added to the foot. No statistical analysis was performed due to the limited sample size.
Figure 4b. demonstrates the problem encountered in the lateral images obtained from patient 5F. The 1\textsuperscript{st} metatarsal which is required to measure the C1MA is out of the image due to the excess room the heel of the shoe acquires. The imaging trials will be repeated for this patient.

Figure 5. is a schematic that demonstrates a common problem with a 2D analysis. The fluoroscope does not strike the foot at exactly 90° causing a distortion of the C1MA angle. This is unavoidable because it is natural to pronate and supinate to some degree during natural gait, further exhibiting why a 3D model is valuable for analysis.
Discussion

The aim of this experiment was to develop a method for the analysis of custom foot orthotics. At the time of the completion of this six week project the research team of graduate students were still at the very preliminary stages of this project. Only two out of the 21 patients to be examined had undergone the fluoroscopic gait trials and neither patient had yet to be CT scanned. In the project, a number of obstacles did and continue to stand in the way the completion.

First, a patient must have their feet molded for the custom made orthotics prior to the imaging date. This molding only occurs at the Fowler Kennedy Clinic in London, Ontario once weekly. The orthotics then take time to be created further adding to a patient’s processing time from start to finish. The fluoroscopy lab is then a shared space. The team had to book specific times and dates and each time reassemble the platform and reposition the fluoroscopes. For imaging to take place an X-ray technician, the patient, the orthotist, and the research team must all be present so coordination also played a role in the delay of the number of patients able to be processed with the allotted six weeks.

Do to the limited progression a 2D analysis was performed using the lateral images from camera A. Note the 3D analysis could not be completed within the six week period because of the inaccessibility for CT scans to be completed at the London Health Sciences Centres. Within the two patients imaged, the first patient’s lateral images were not able to be used in the 2D analysis. It was discovered that the 1st metatarsal which was needed to measure the calcaneal-first metatarsal angle (C1MA) was not in fact in the image and instead the medical cuneiform bone was the bone seen in the image frame. This failure to capture the 1st metatarsal which is situated farther down from the medial cuneiform bone was due to a combination of having an image intensifier (II) with a small diameter in the lab and the patient having made their initial heel strike prematurely. This error was corrected for future patients by using floor markers to indicate where the left heel imprint should approximately begin for optimal results.
The 2D analysis also brought upon the problem of out of plane rotation. For the C1MA angles to be accurate the X-ray source was required to strike the arch at precisely 90°. Do to the natural tendency of the foot to pronate or supinate during normal gait this assumption was not realistic and further demonstrates the need for a 3D model. The lone patient to yield C1MA values came from the normal subcategory. As the patient progressed from walking barefoot to a neutral shoe to one with an orthotic the C1MA decreased. This result was expected though not statistically determined whether significant due to the limited sample size.

The future of this experimental will include the completion of fRSA resulting in a complete 3D model in-vivo with time through normal gait. This novel technique of fluoroscopic radiosteriometric analysis has already demonstrated its ability to outperform the previous method of using a camera-based optical tracking system with regards to testing a phantom under ideal conditions (Kedgley et al. 2009). It is expected that this method for orthotic analysis will be require another five months for completion, but by testing the three subcategories it will provide valuable research for the orthotic industry.

**Conclusions**

The aim of this six week project was to use fluoroscopic radiosteriometric analysis (fRSA) to create a method for orthotic analysis. The focus of this research is primarily the ability to create an accurate three-dimensional model of a foot in dynamic motion and from that point onwards analyse the individual orthotic types and molding techniques. Though this project is far from completion the technology proposed stands to provide the foundations that could potential solve many biomechanical problems. The familiarity of fRSA and its components may soon offer not only industry standards to the development of custom made orthotics but also change to how pre and post surgical interventions are studied.
Acknowledgements

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References


