Exploring the use of non-image-based ultrasound to detect the position of the residual femur within a stump

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A satisfactorily-fitted socket interacts dynamically with the stump, transmits loads effectively, enhances dynamic stability, and enables the control of the residual limb. To this day, very little is known about the movement of the amputated bone within the stump and its effects on the gait or the residual muscles of the amputees. Current measurement techniques of the skeleton (mainly with the use of x-rays) within the prosthetic socket have not sufficiently addressed the question of how load transfer is performed during dynamic movements. Thus, there is a need to utilize a new method to record the internal dynamics of the stump, while it is enclosed within a socket. Ultrasound was chosen as it has no known ill effects.

This study aims to gauge the effectiveness of our instrumentation, and determine the errors expected from the ultrasound measurements.

Methods

The PCM 8 Channel 100MHz Ultrasound platform system from INOSON (St. Ingbert, Germany) with 2MHz transducers were selected for this study. The received signals from this ultrasound system are recorded as a waveform trace.

Validation of the ultrasound system was performed in 2 stages. First, ultrasound measurements of the motion of a rod in a water tank (Figure 1) were compared with measurements from Qualisys (Gothenburg, Sweden) 3D motion capture system. The rod measured 2x3x20cm and was used to determine, if the ultrasound could differentiate adjoining materials. As depicted in Figure 1, the rod was made of a 1cm thick aluminium-alloy and a 2cm thick steel alloy attached together with Pattex Ultra Gel (Düsseldorf, Germany). We moved the rod in the water bath, and determined the distance between one edge of the rod from an ultrasound transducer, and the thickness of the alloys.

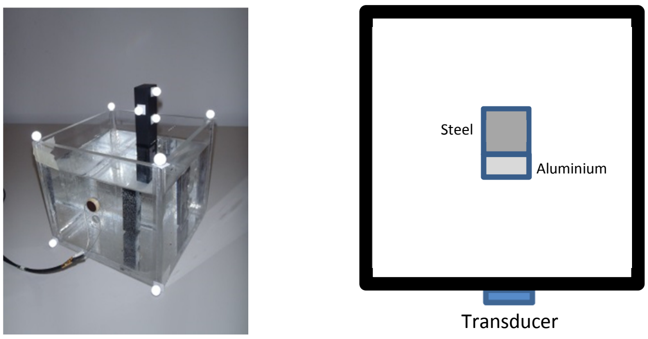

Figure 1: A double-material rod in a water bath with Qualisys markers.

Secondly, ultrasound measurements were performed on a normal subject at 5 different positions along the thigh. Markers visible in Magnetic resonance imaging (MRI) were attached to the same positions (Figure 2) as the ultrasound transducer. A scan was performed with a 3T whole-body MRI scanner (Magnetom Trio, Siemens Healthcare, Erlangen, Germany). Bone positions in the thigh calculated from MRI data were compared with ultrasound measurements.

Figure 2: MRI data of one subject with MRI markers.

Results and Discussion

A single ultrasound transducer was sufficient to detect the position of the rod in the water bath with an error of 0.16±0.07cm. It could differentiate the interface of the adjoining alloys with an error of 0.20±0.13cm. In a water bath, given the liquid-solid (water-rod) interface, a clear ultrasound signal was obtained. Errors obtained were acceptable and demonstrated that our setup in using an ultrasound system, which provides a waveform trace instead of an image, can be applied to provide the position of a rod within a water bath.

Obviously, higher errors are expected in human subjects; possible contributors are subject motion during recordings and attenuation of the soft tissues. Since our goal is to determine the position of the bone in a stump, we are particularly concerned about the high attenuation occurring when the transmitting pulse hits the bone. This is because acoustic impedance of bone is very different from its surrounding soft tissues. The use of 2MHz transducers did provide recordings of deeper structures like the femur, which is approximately 5-7cm within a stump. Our ultrasound data was compared with MRI data, and errors of 0.23±0.18cm were found, which we found to be acceptable.

Current impact of ultrasound measurements in lower limb prosthetics, together with the recording of an ultrasonic waveform trace, is limited. In this study, an estimate of the errors of an ultrasound system to detect the position of the femur has been performed. This is a first study and we hope to continue and enhance these methods such that they can be applied to amputees. Repeating the study on an amputee, we expect some further problems due to the coupling between the ultrasound transducers and the socket. This may result in poor recordings. However, the advantages with the use of ultrasound equipment, such as its low cost, light weight transducers, portability and ease of use, may play a huge part in the biomechanical understanding of the internal dynamics within the stump. So, the application of ultrasound during socket fitting will become a standard feature, if its efficacy and accuracy can be determined during normal amputee gait.