Ultrasound Pre-study of the Kinematics of the Residual Tibia within a Trans-Tibial Socket during Gait

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Abstract— **The motion of the residual-tibia within a trans-tibial socket was examined so far only by X-ray. In this pre-study now the motion of the residual tibia is to be described during gait using ultrasound data. The results of measurement raised here are to serve as input for later simulation work, in order to be able to adapt socket fit individually.**

So far, this procedure of ultrasound measurement during gait cycle was used only related to the femur.

In the first part the structure of the test rig and the integration into the socket is described, as well as the calibration of the system. In the second part, the results of measurement are represented and discussed afterwards.

Keywords— **ultrasound, trans-tibial, relative motion, prosthesis, gait.**

I. Introduction

Eriksson and Lemperg (1969) [1], Grevsten and Eriksson (1975) [2] and Lilja et al. (1993) [3] all used radiographic techniques to analyse residual tibial movement within trans-tibial sockets. Mayfield et al. (1977)[4], Sabolich (1985)[5] and Long (1985)[6] also used radiographic techniques to the analysis, however they were occupied with the motion of the residual femur within the trans-femoral socket. The use of radiographic technique is possible only temporarily because of the risk of ionising radiation. Furthermore these studies were restricted to static analysis at simulated instants of the gait cycle.

Convery and Murray (2000) [7] used the ultrasound for the examination of the residual femur motion within a trans-femoral socket during gait cycle for the first time.

The ETH Zurich developed in 2006 a „moving-video-fluoroscope“, a C-arm-x-ray unit, which is carried with the patient. Thus it permits recordings of the knee-TEP during a complete gait cycle [8, 9]. This procedure was used only to analyse TEP knee joints so far.

This pre-study measured the motion of the residual tibia within a trans-tibial socket during gait using ultrasound for first time.

Four 9MHz linear array transducer were selected in order to provide an optimal image of the tibia. The field of view of all four transducers is 39mm and each transducer was connected to a separate diagnostic ultrasound scanner EchoBlaster128 (Telemed, Lithuania).

By mounting the ultrasound transducers on the outside wall of the socket it is possible to set the movement of the Tibia within the socket direct in connection to the socket. However, overruns may occur due to poor contact at the interface between transducer and stump during gait cycle. This can be prevented and/or minimized by exact positioning of probes in forward, an optimal socket fit and the use of "Sonar Aid" (Geistlich Pharma, Switzerland), aqueous coupling medium for diagnostic ultrasound.

Also out of this the necessity can be derived that for each measurement an individually manufactured and adapted prosthesis socket will be required.

II. Subject

The subject is a 27-year-old male whose left trans-tibial amputation was a result of an osteogenic sarcoma. He is 1,82 meter tall and weights 72 kilogram. The subject was amputated for 11 years at the time of the preliminary study. He carries his prosthesis daily about 16 hours, is vocationally main sitting actively and is due to its private activities assigned to the activity class IV.

III. Methodology

For the production of the measuring socket at first a test socket was manufactured out of „Thermoflex solid“ (Bauerfeind, Germany) within a 3mm soft wall interior socket out of „Extrafoam “ (Leder Scheben, Germany).

At the measuring socket, four ultrasound transducers were positioned in such a way that the Tibia is on target during the entire gait cycle. Subsequently, two points of reference were specified: proximal the Tuberositas tibiae and distal at the end of the tibia, to those in each case two ultrasonic probes were anterior and laterally aligned. For stabilization serves a metal-rack, which fix the probes by means of cube caps. Threaded rods and axial pivots connect

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the mounting plates and thus avoids the change in angle of the probes among themselves.

According to this model the measuring socket could be manufactured. As placeholder for the ultrasound transducer dummies from gypsum were manufactured. Armoring consisted of four layers stockinette, four layers glass, carbon fiber amplification, and the whole was filled up with carbon acrylic resin. The finished measuring socket with the integrated ultrasound transducers and the metal-rack is to be seen in fig. 1.

In each case the four ultrasound transducers were assigned to an IPC (Bressner, Germany). These IPCs contain an Intel Core2Duo processor with 1,6GHz and 2GB DDR II RAM main memory. USB 2.0 connect the diagnostic ultrasound scanner with the IPCs. The four IPCs are interlaced over a SWITCH among themselves. All devices of the measurement setup are supplied via a voltage supply with 12VDC.

The four measuring systems were appointed before beginning of each measurement with the help of DCF77-receiver for accuracy in the same time. This time serves for the synchronisation of the measurements.

The entire ultrasound measuring system is on a trolley, which was motor driven over a belt drive beside the subject.

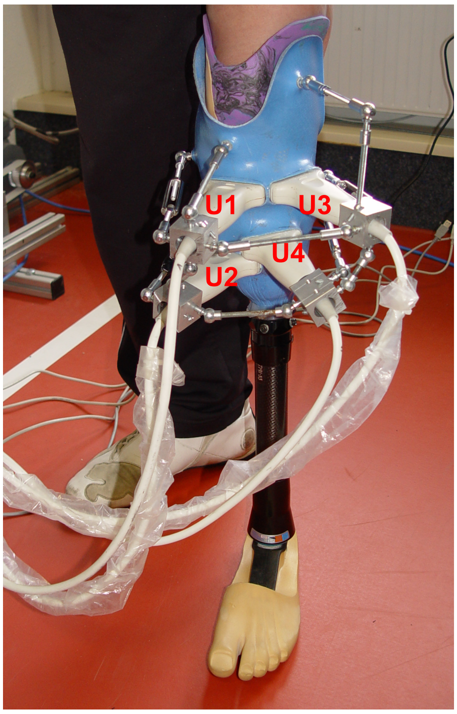

Fig. 1 Measuring socket with integrated transducers

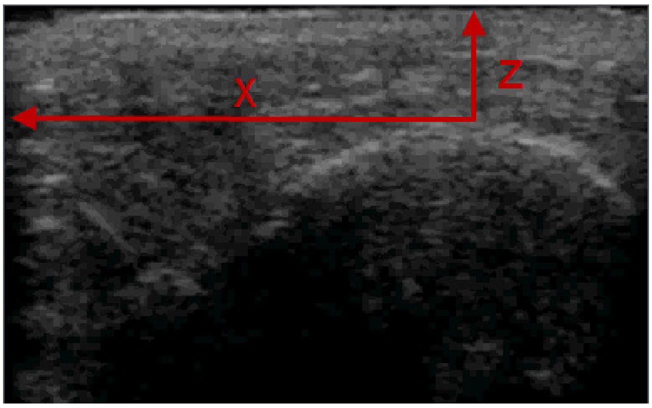

Fig. 2 Ultrasound measurement of the Tibia with the transducer 2

For calibration of the measuring system three long parallel rods with 5mm targets were incorporated centrally in the socket, parallel to the socket axis. The socket was filled with water and the position of the rods in the socket was compared with the values of the ultrasound measurement.

A 3-dimensional x, y, z co-ordinate system was adopted for measurement purposes. The z distance was measured perpendicular from the transducer surface to the measuring object. The x distance was measured parallel to the transducer, from the lateral border of the field of view to the measuring object. The distance y indicates the measurement from the deepest point of the Patella support, the relative depth of the measuring object within the socket. It was measured using a height gauge. Figure 2 illustrates the ultrasound image of the residual tibia-end within the socket as a semicircular arc and the transducer surface as the horizontal line across the top of the screen. The x and z co-ordinates lie at the apex of the arc.

The ultrasound transducers 1 and 2 lie approximately parallel to the posterior brim of the socket. Tibia motion perpendicular to the sensing surface of the transducers 1 and 2 was considered to be flexion/extension relative to the anterior socket wall. Tibia motion parallel to the sensing surface of the two transducers was considered to be abduction/adduction relative to the anterior socket wall. The measured ultrasound data was transferred to spreadsheets.

By the knowledge about the orientation of all ultrasound transducers to each other and these, again to the axle center of socket, the angle changes of the Tibia movement can be computed. The flexion/extension of the Tibia on each moment of the gait cycle was computed over the formula 1.

$$\tan \alpha = \frac{(zU2 - zU1)}{(yU2 - yU1)} \tag{1}$$

Abduktion/adduktion of the Tibia was computed over the formula 2. The ultrasound transducers 3 and 4 were evaluated as check measurement.

$$\tan\beta = \frac{(xU1 - xU2)}{(yU1 - yU2)} \tag{2}$$

A Qualisys Motion Capture system (Qualisys, Sweden) seizes „the outside "kinematic data. Thirteen retro-reflective markers were placed after the Oxford Foot Model on both sides of the subject. Two parallel hall-effect-force-plates (AMTI, USA) and the NOVEL pedarX system (NOVEL, Germany) supply kinetic data. The Qualisys program as well as the NOVEL system and the force-plates serve the momentary gait phase as reference values for the clear regulation.

The pre-study was accomplished in the gait-laboratory of the department of Orthopaedics and movement systems of the Fraunhofer Institute for Manufacturing Engineering and Automation in Stuttgart.

The patient moved in a self-chosen and pleasant cadence and speed for him. In ten going attempts by four measuring transducers the distances between bone edge and socket wall, as well as the kinetic and kinematic parameters were determined.

IV. Results

Further the measurements take place at present, results up to the expiration of the term are supplied later.

V. Discussion

Discussion is supplied later.

VI. Conclusions

Conclusions are supplied later.

Acknowledgment

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