THREE-DIMENSIONAL MEASUREMENT OF THE GEOMETRY OF THE HUMAN MOTION APPARATUS

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INTRODUCTION: This work is part of a project of the Department for Sports Medicine, University of Tübingen, to establish a biomechanical model to calculate the internal stresses arising when jumping from a squat position. The goal of the project is to facilitate individual calculations. Therefore the model is designed to obtain the major anatomical-geometrical and physiological quantities as parameters. These quantities are acquired by electromyogram (EMG) and radiological measurement. The procedures for the acquisition and reduction of the radiological data are described here.

METHODS: As the study did not involve pathologies, ionizing radiation was ruled out, and magnetic resonance imaging (MRI) was used. The biomechanical model requires geometrical parameters from joint positions beyond those occurring during the squat-vault.
Good spatial resolution and short acquisition time are facilitated by the magnetic resonance scanner Siemens Magnetom Impact, with a magnetic field strength of 1.0 Tesla; therefore this device was chosen for the measurements at straight leg position. A T1 weighted spin-echo sequence (TR/TE: 500 ms/15 ms) with 5mm slice thickness, 10 mm slice distance and 400 mm field of view (matrix 256^2) was used. The entire lower motional apparatus was scanned in consecutive blocks.
For non-straight joint angle positions the MRI scanner Siemens Magnetom Open was used. Because of the relatively low magnetic field strength (0.2 T), this device offers a lower signal-to-noise ratio and requires longer acquisition times, but it allows for almost unlimited movement in the table plane. Different measurement parameters were evaluated. As the length of the field of view was about 25 cm, the different joints had to be scanned separately. A positioning table was used to serve three purposes:

1. Positioning with defined joint angles, so the morphology could be related to the EMG measurements.
2. Exertion of force, to measure the geometry of muscles and tendons under strain.
3. Placement of markers with high MRI contrast, to relate the relative position of the scans of the different joints.

In a pilot study different sequences for the Magnetom Open measurements were evaluated:
T2-weighted spin-echo-sequence (TR/TE 3300 ms/117 ms, 2 acquisitions averaged);
T1-weighted spin-echo-sequence (TR/TE 360 ms – 510 ms/15 ms, 3 acquisitions averaged);
T1-weighted gradient-echo-sequence (TR/TE 40 ms/10 ms).

A body coil was used, the matrix size being 256², slice thickness and slice distance 10 mm.
The evaluation of the images was done using the software 'Tübinger Medstation' developed by the Department of Computer Science at the University of Tübingen, and "Mimics" from Materialise N. V., Belgium.

RESULTS:
Open MRI scanner measurements:
As expected, the use of T2 weighted sequences resulted in better soft tissue contrast; especially the fat contained in the muscles could be distinguished, defining the direction of the muscle fibers (Fig. 1a). However, the T1 weighted spin echo sequence was preferred for its shorter acquisition time, which was an important factor because measurements had to be made under strain. Bones and tendons, with their low hydrogen content, produce weak signals in MRI and thus contrast with the adjacent soft tissue. Here and for the detectability of the fascies the T2-weighted images offered no advantage over the T1-weighted (Fig. 1b). Even shorter acquisition times by use of a gradient sequence were ruled out because of their low signal/noise ratio, which rendered the fascies undetectable (Fig. 1c).

Fig. 1:
a) T2-weighted spin-echo acquisition, TE=117 ms, TR=3300 ms.
b) T1-weighted spin-echo acquisition, TE=15 ms, TR=420 ms.
c) T1-weighted gradient-echo acquisition, flip angle 40°, TE=10 ms, TR=40 ms.

Automatic segmentation of these fascies is extremely hard to achieve. The 'Medstation' software was used to extract coordinates of muscle and tendon insertions by hand (Fig. 2). In this way, tendons, muscles and bones were segmented (Fig. 3).

Measurements at a magnetic field strength of 1 Tesla, straight leg position:
The measurement blocks were combined, and as described above the following anatomical structures were extracted:
Bone, Vastus lateralis and medialis, Rectus femoris, Gluteus maximus, Biceps femoris, Semitendinosus, Gastrocnemius lateralis and medialis, Soleus (Fig. 4).

CONCLUSIONS: A procedure has been developed to extract the geometrical data of muscles, tendons and osseous structures important for the biomechanical model. For this model**,** extended muscle and tendon insertions have to be reduced to a point by calculation of the center of mass of the insertion area.
Currently, MRI measurements for three different types of athletes at all joint angles of interest are being carried out. At the same joint angles, defined by the positioning plate, torque measurements will be made in the Department for Sports Medicine. Since these torques result from the combined action of several muscles, it would be helpful to obtain the maximum force of each muscle from its geometrical parameters at different contraction states. Therefore we will try to establish such a muscle correlation model.

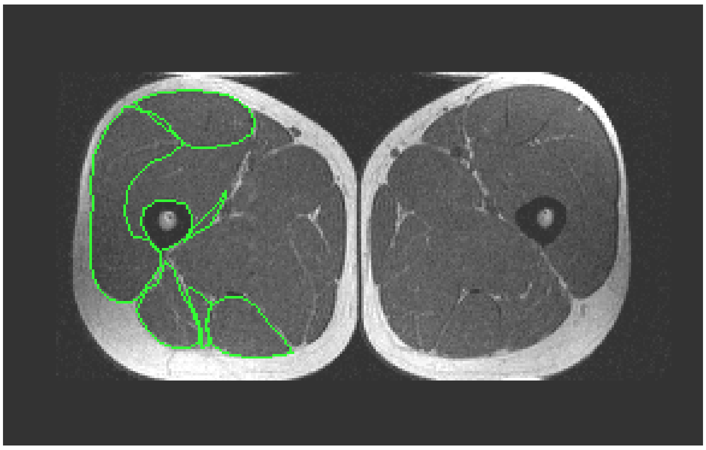
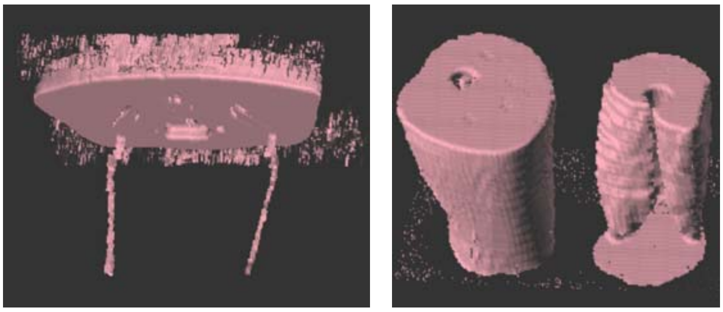


Fig. 2: Section through the thighs with segmented anatomical structures. (Scanner: Siemens Magnetom Impact).



a) b)

Fig. 3: 3D-Reconstruction of the tendon of m. rectus femoris (a) and m. quadriceps femoris (right leg; left leg: skin surface) (b). (Scanner: Siemens Magnetom Open).

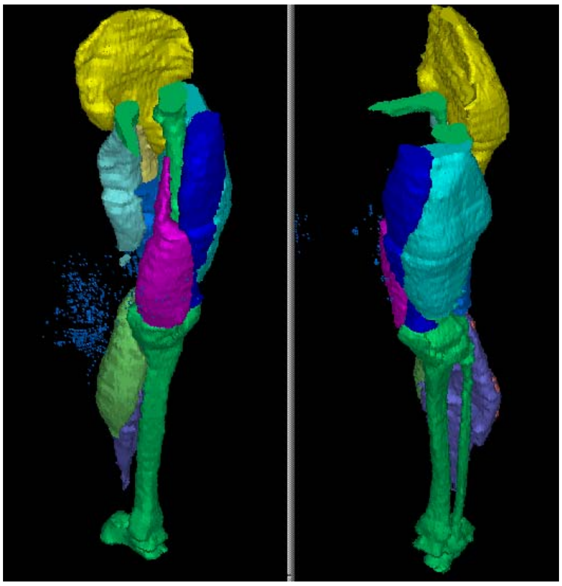


Fig. 4: Bone, vastus lateralis and medialis, rectus femoris, gluteus maximus, biceps femoris, semitendinosus, gastrocnemius lateralis and medialis, soleus, segmented from combined measurement blocks at straight leg position. (Scanner: Siemens Magnetom Impact).

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