IN VIVO QUANTIFICATION OF 3D KINEMATICS AND CONTACT AREAS OF THE PATELLO-FEMORAL AND TIBIO-FEMORAL JOINTS

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Introduction:
Patello-femoral disorders are often attributed to malalignment and maltracking of the patella [1]. The reason for the altered patellar kinematics is frequently not located in the patello-femoral joint, but may also be caused by changes of femoro-tibial kinematics [2]. Until now no study has investigated both kinematics simultaneously. However, for a causal treatment knowledge about patello-femoral and femoro-tibial kinematics is necessary. Beside the investigation of patellar kinematics the identification of altered patello-femoral contact pattern is clinically important, to detect areas with potentially increased contact pressure which may damage articular cartilage.

The objective of this study was to develop a technique which allows for the first time to determine patello-femoral contact areas and simultaneously 3D kinematics of the patello-femoral and tibio-femoral joint in vivo and under the influence of normal muscular activation.

Material and methods:
The knee joints of 10 healthy volunteers (22 – 36 y.) were investigated. Kinematics analysis was performed in an open MR system (0.2 Tesla; Magnetom-Open, Siemens, Germany) at two different flexion angles (30° and 90°) with external loads being applied during imaging. A T1 weighted 3D GRE-sequence (TR 16.1 ms, TE 7.0 ms, flip angle 30°) was used, the image acquisition being performed in sagittal orientation. The acquisition time was 4:26 min. and the in-plane resolution 0.86 mm.

Digital Image processing
After image acquisition and data-transfer onto a parallel computing system, segmentation and 3D reconstruction of the femur, patella and tibia were performed. To analyze patello-femoral kinematics a patella-based local coordinate system (PBCS) was calculated to determine the position of the patella relative to the femoral trochlear groove. Based on the segmented tibia plateau, the 2nd eigenvector was determined using principal axis decomposition. Finally, the position of these reference points of the femur and tibia were projected in the PBCS (Fig. 1). This allowed to determine the usually used 2D parameters to describe patello-femoral kinematics following the international literature [1,3] three-dimensionally.

To determine tibio-femoral kinematics, a tibia-based local coordinate system was calculated based on its spatial orientation, with its origin in the centroid of the tibia plateau. Femoral reference points were defined that are unaffected by knee flexion. Therefore a cylinder fitting the centroid of the tibia plateaus. Femoral reference points were defined in this way. To determine the 3D position of the femur relative to the tibia (Fig. 2a), To analyze the femoro-tibial and femoro-patellar contact areas, each cartilage was segmented and stored in separated data volumes. In this way the segmented data voxels were defined as value “1”, the unsegmented voxels as value “0”. In a next step for each data volume the contour was calculated. Therefore this data volume was eroded by 1 voxel and then subtracted from its original volume. At least both volumes were added and the voxels with the value “2” in the added data volume define the contact areas (Fig. 2b).

Results:

Reproducibility of the image processing technique
The reproducibility of the tibia- and patella-based coordinate system demonstrated a coefficient of variation (CV%) of 0.3 % and 0.2 % respectively. The patello-femoral and femoro-tibial displacement also displayed high reproducibility with a CV% of 3.8 % and 4.7 %.

Effect of knee flexion (30° - 90°) on patellar kinematics
In the vertical plane the patellar tilt decreased in all investigated knees significantly during knee flexion (9.2°±3.3° vs. 5.0°±3.0°). The patellar shift to lateral remained in both investigated positions almost unchanged with values below 2 mm. Also the 3D sulcus angle for each individual was constant in both positions (144.7°±6.4°). In the sagittal plane the femoro-patellar angle increased significantly during knee flexion (15.3°±9.3° vs. 9.9°±2.6°).

Effect of knee flexion (30° - 90°) on femoro-tibial displacement
During knee flexion, significant posterior translation of the femur relative to the tibia was observed. Due to the additional external rotation the amount of translation was higher for the lateral condyle.

Effect of knee flexion (30° - 90°) on contact areas
At 30° of knee flexion the femoro-patellar contact areas were located in the middle of the patellar articular cartilage, the contact being distributed across a broad transverse band. The size of the contact areas was 112.7 mm² ± 33.3 mm². At 90° of flexion the contact areas migrated superiorly, the size being significantly higher (355.8 mm² ± 41.5 mm²).

Conclusions:
In this study, we have developed and applied a 3D MR-open based imaging and postprocessing technique to assess tibio-femoral and patello-femoral 3D kinematics in vivo and under the influence of normal muscular activation. Additionally we determined the size and location of the patello-femoral contact areas. With this technique we were able to overcome the limitations of previous in vivo investigations, by avoiding the restriction of the analysis to one plane, limited reproducibility and the limited flexion angles. The results demonstrate that this method is highly reproducible. This technique has the potential to provide new in vivo information about the kinematics of the patella, which can help to improve diagnostics and treatment of patello-femoral disorders.

References: