RELATIONSHIP BETWEEN THE DISTAL FEMORAL MORPHOLOGY AND CRUCIATE LIGAMENT ATTACHMENTS

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INTRODUCTION AND OBJECTIVES

The mobility and stability of the human knee joint are influenced mainly by the complex interaction between bony and soft tissue structures. If the ligamentous situation is not compatible to the bony geometry, the biomechanics of the knee joint will be altered, possibly leading to joint surface damage [Daniel1994]. Furthermore, if the joint surface is deformed through arthritis, a traumatic fracture or changed by an artificial implant, knee biomechanics will be disturbed as well [Sharma2012]. Therefore, harmonized systems are crucial for physiological ligament function and overall knee kinematics, which should be considered in, e.g. cruciate retaining implant design, posterior stabilized implants and cruciate ligament replacement.

Menschik et al. found a direct correlation between knee morphology and cruciate ligament attachments by introducing a 4-bar linkage, assuming that the lengths of the cruciate ligaments remain unchanged during knee flexion [Menschik1974]. The presence of approximately isometric fibres in passive motion could be confirmed by Belvedere et al. [Belvedere2012]. Eckhoff et al. stated that a cylindrical axis, a line equidistant from the surface of the posterior femoral condylar surface, passes directly through the origins of the ACL and PCL [Eckhoff2007].

The goal of this study was to analyze the relationship between distal femoral morphology and cruciate ligament attachments by (1) using segmented cruciate ligament attachments based on MRI-datasets (2) developing a robust framework for reliable and automatic identification of the articular geometry for an appropriate comparison.

MATERIALS AND METHODS

The cruciate ligament attachments were segmented in 6 MRI-datasets (n=6) from healthy male subjects (BH 184±6cm, BW 90±10kg) by a clinical expert in the medical image software Osiris. The insertion areas were approximated by lines in each slice and exported as point cloud, which resulted in a random point distribution. A self-developed program in MATLAB was used to resample the points with a homogeneous distribution and to project the points onto the 3D bony surface. Furthermore, the femoral epicondyles were selected to determine the transepicondylar axis (TEA) as further reference.

The articular geometry was analyzed based on the framework proposed by Li et al. [Li2010] and implemented in MATLAB. A graphical user interface was programmed to handle and visualize the in- and output and to start the calculation (Fig. 1). The input consisted of a triangulated surface mesh (STL-format) of the distal part of the femur and the default sagittal plane (DSP). In the rare case of an initial misalignment it was possible to manually adjust the DSP.

The bone surface was passed to the main function that calculated the unified sagittal plane (USP). Therefore, two cutting boxes each filled with 8 parallel cutting planes were positioned on the most posterior point of each femur condyle. The orientation of the boxes was varied in an iterative manner. For each variation the articulating parts of the contour profiles defined by the cutting planes were determined. Ellipses were fitted to the contour parts and the 2D dispersion of the posterior foci of these ellipses was calculated. The variation with the smallest dispersion was defined as the USP. The elliptical axis (EA) was fitted to the 3D positions of posterior foci with minimum dispersion. According to Li et al. the radius of the flexion facet, which is the approximation of the posterior articulating surfaces, varies substantially with the segmentation location, why the femoral condyles should be modelled as ellipsoidal surfaces. Additionally, the center of the smallest flexion facet is in close proximity to the focus of the ellipse.

Improvements have been made to the iteration process. The approximate position of the dispersion minimum was localized by a rough search with a larger step size of the plane variation. Subsequently an automatic fine search with a plane variation of 0.5° was performed around the dispersion minimum, reducing the number of iterations by about a factor of 10 compared to the method described by Li et al. In addition parallel computing was implemented for the computationally-intensive algorithm to calculate the contour profiles to reduce computing time.

Finally, the centroids of the cruciate ligament attachments were directly compared to the corresponding TEA and EA by projecting the ligament insertions to a plane, orthogonal to the appropriate reference axis.

RESULTS AND DISCUSSION

The implemented framework for the determination of the EA was able to process all STL-data of the distal femora within 5 min per subject on a normal computer (Fig. 2). Regarding the progression of the 2 axes, there was only in 1 subject with an intersection of the TEA with the intercondylar notch. For all other subjects the TEA passed through the solid femoral bone. Thus, the TEA cannot pass inevitably through the origins of the cruciate ligaments. The EA intersected the intercondylar notch for all subjects invariably, which agrees with the results of Eckhoff et al.

The projected cruciate ligament attachments for the EA and TEA are presented in Fig. 3 and 4. Looking at the point distributions of the insertions, ACL and PCL are clearly separated for both axes. Concerning the EA, the ACL insertions were located slightly proximal/anterior and for the PCL anterior. The mean distance between ACL and EA was 10.12±3.41 mm and 20.32±1.43 for the PCL, respectively. Despite the high deviations, particularly regarding the PCL, the variance was only 2.06 mm. Regarding the TEA, the distances were smaller but for the PCL the variance was higher, indicating a less functional relation to the knee joint, coinciding with the findings of Hancock et al. [Hancock2013].

CONCLUSION

In this study, the cruciate ligament attachments of the distal femur, represented as the centroids of the insertion areas, were compared to the pathways of the TEA and EA in order to investigate the correlation between attachments and morphology. The results imply that there is at least a correlation between the EA and PCL attachment. However, the TEA showed a less functional relation. Therefore, the EA could provide additional knowledge for patient-specific therapy based on CT-data where no soft tissue information are available.

Limitations are the small number of data-sets and the assumption of a single insertion point.

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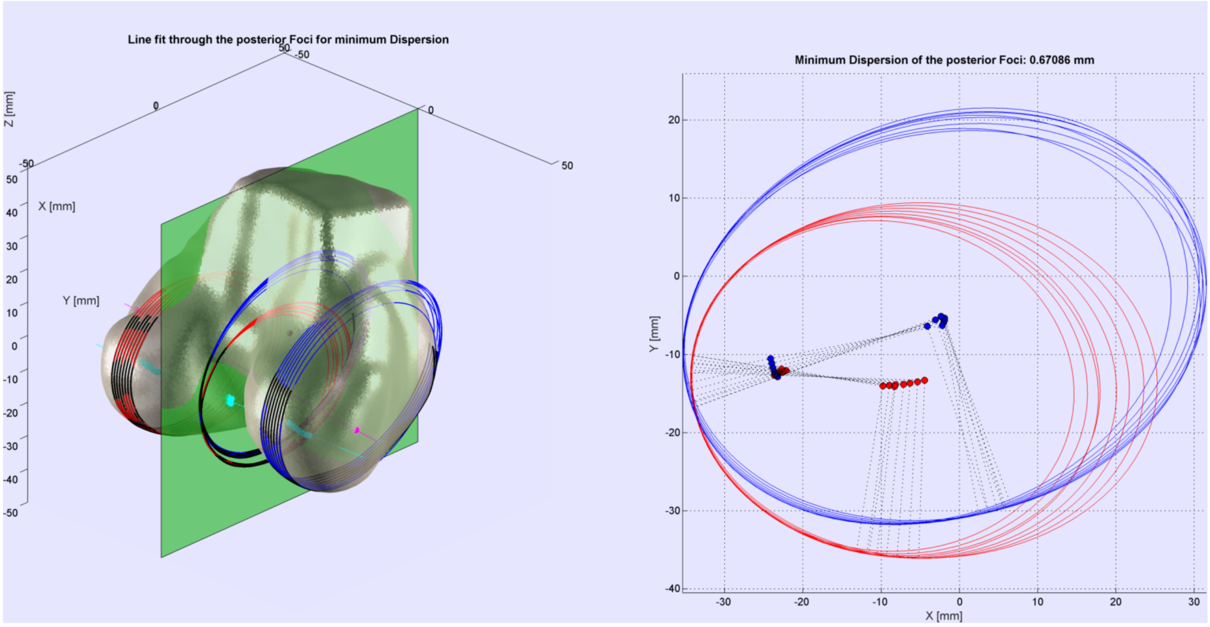

Fig 1: GUI, left: distal femoral bone with fitted ellipses, right: unified sagittal plane with dispersion

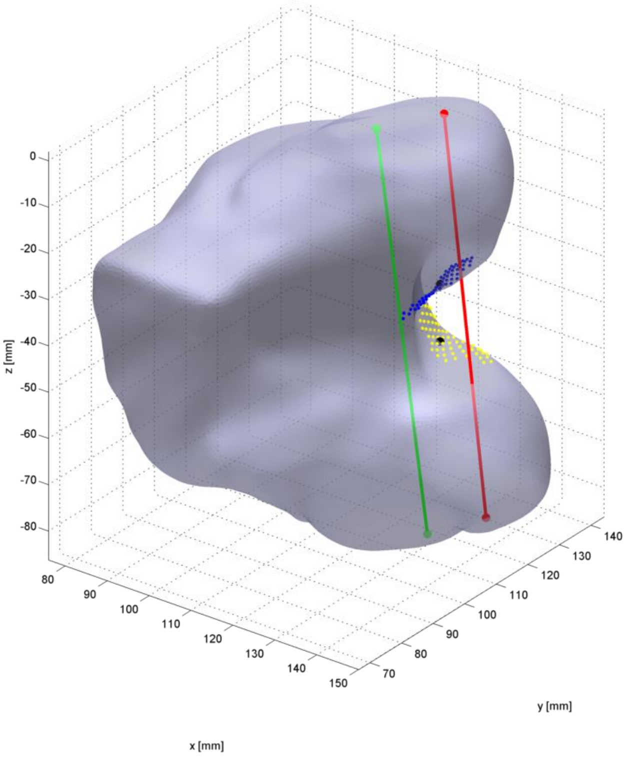

Fig 2: Exemplarily visualization of the reference axes, green=TEA, red=EA, blue=ACL, yellow=PCL

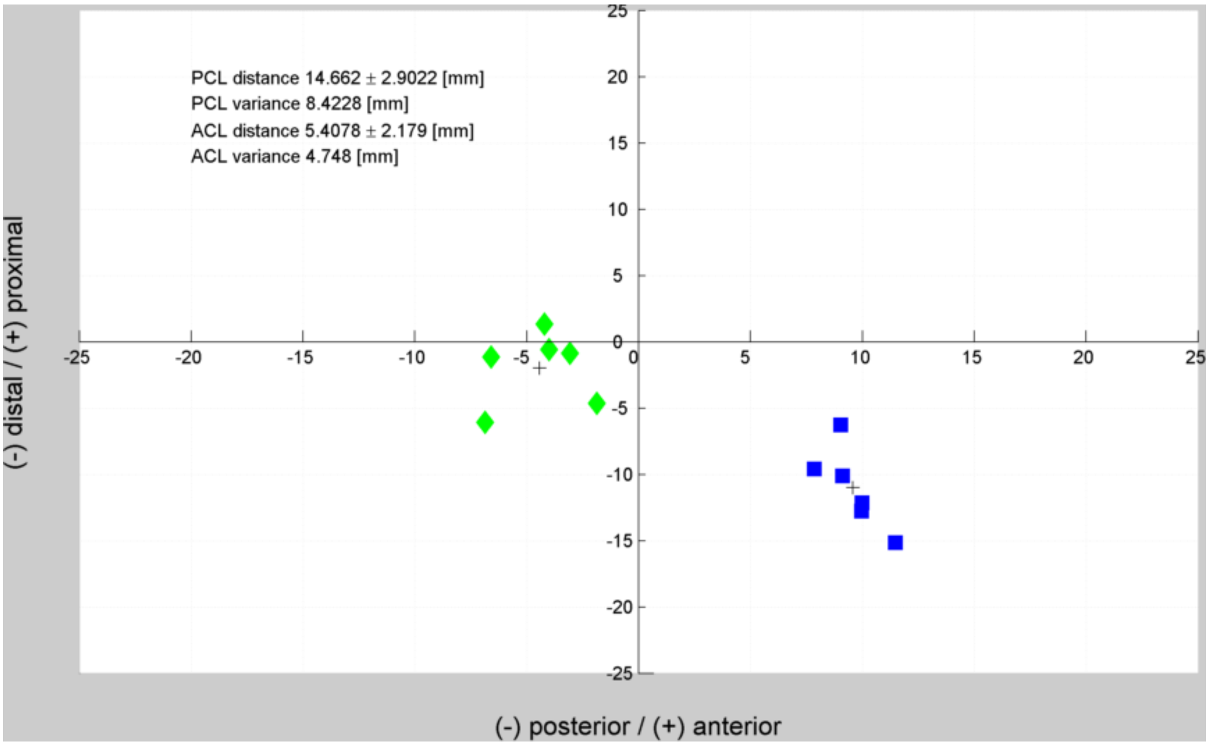

Fig 3: Cruciate ligament attachments (n=6) projected along transepicondylar axis (TEA), ACL=green, PCL=blue

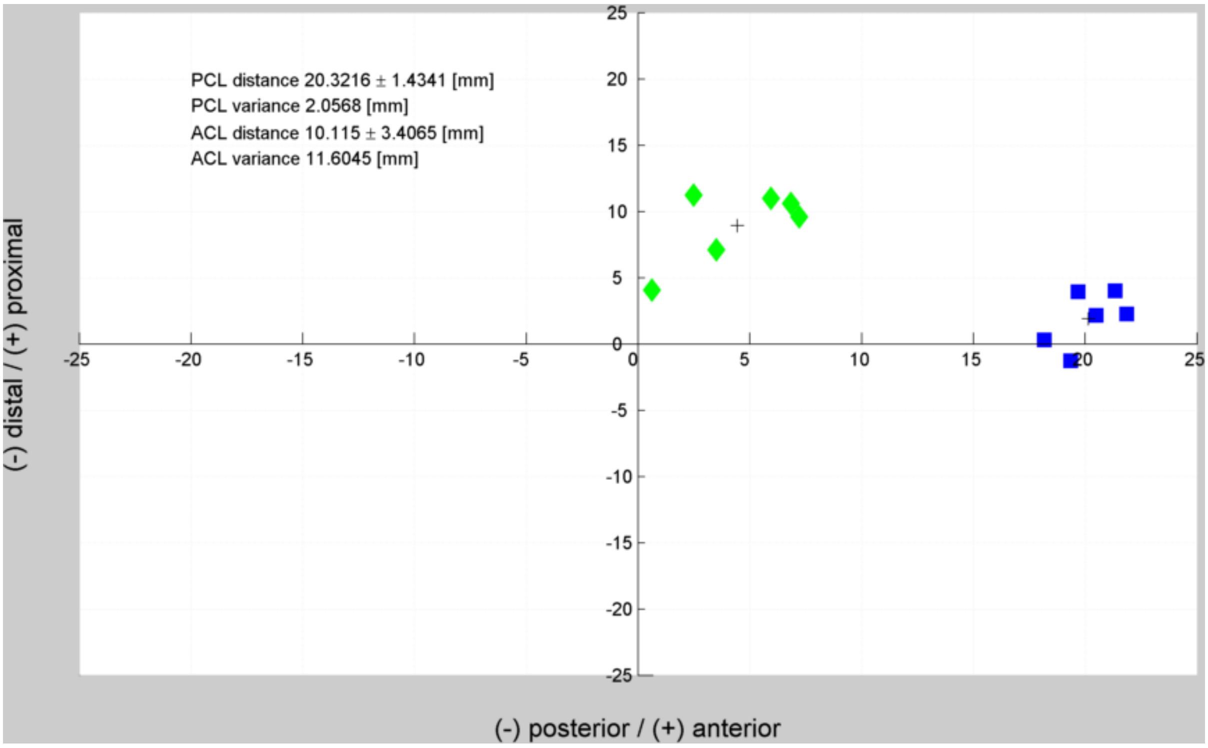

Fig 4: Cruciate ligament attachments (n=6) projected along elliptical axis (EA), ACL=green, PCL=blue