Influence Of The Cruciate Ligaments On Tibiofemoral Gaps

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INTRODUCTION: Implant alignment and the resulting knee stability are important factors that have an impact on the short- and long-term results of total knee arthroplasty (TKA) [1]. To date, TKA requires resection of the anterior cruciate ligament (ACL) or even resection of both cruciate ligaments. While changes of the tibiofemoral gaps after posterior cruciate ligament (PCL) resection have been discussed widely in the literature [2], the influence of ACL resection on tibiofemoral gaps and thus the native soft-tissue balance remains mostly unknown since gaps in the native knee have usually been measured after tibial-cut and resection of the ACL. Therefore, the aim of this study was to quantify the tibiofemoral gaps of native knees at different flexion angles prior to tibia and ACL resection and to investigate changes after gradual ACL and PCL resection.

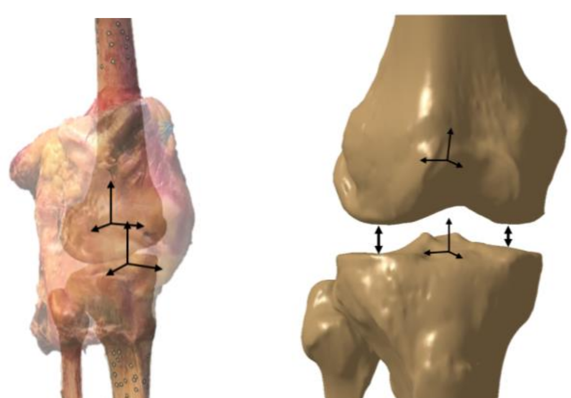
METHODS: Nine fresh-frozen human cadaveric knees [3] were tested on a six degrees of freedom joint motion simulator (AMTI VIVO) by applying 100 N distraction force for 25 s at different flexion angles (0°, 30°, 45°, 60° and 90°) and different resection stages (native knee, after resection of the ACL and after resection of both cruciate ligaments) with all other forces/moments maintained at 0 N/Nm. In order to track the relative position of femur and tibia during testing, each specimen was subjected to a complex 3D fitting process (ARAMIS 12M, Carl Zeiss GOM Metrology GmbH). During this process, segmented CT scans containing landmark-based femoral and tibial coordinate systems were aligned with the skeletonized proximal and distal segments of the joint (Fig. 1a). Knowledge of the relative positions of the femoral and tibial coordinate systems and their corresponding bone geometries during testing allowed subsequent measurement of the tibiofemoral gaps between the most distal points on the femur and on the tibia plateau medially and laterally along the mechanical axis of the tibia (Fig. 1b). The measured gaps were normalized to the native medial gaps at 0° flexion to allow comparison between the specimens and stages of resection.

RESULTS: For all specimens, the native lateral gaps were larger than the medial gaps throughout the entire range of flexion (Fig. 2). Furthermore, the native medial and lateral gaps were tightest in extension and showed a convex progression throughout the range of flexion with a markable increase until 30° flexion. ACL resection resulted in different behavior of the gaps during late flexion, which can be divided into two main groups. In group 1, the medial and lateral gaps showed a markable increase during late flexion compared to the native situation, indicating the influence of the ACL. In contrast, gaps remained almost identical to the native situation in group 2. After resection of both cruciate ligaments in group 1, the gaps remained nearly the same as after ACL resection, whereas in group 2, the gaps showed a markable increase medially and laterally during late flexion.

DISCUSSION: After gradual resection of the ACL and PCL, different behaviors of the gaps during late flexion were identified, indicating individual differences in cruciate ligament function. However, the markable increase of the native tibiofemoral gaps until 30° flexion almost remained the same after ACL resection and after ACL + PCL resection. As a consequence, balancing the knee at 0° and 90° flexion during the surgical procedure may not lead to the goal of stabilizing the knee throughout the full range of motion since the gaps show a convex rather than a linear progression. This may imply an anatomic cause for mid-flexion instability after gap-balanced TKA.

SIGNIFICANCE: This study demonstrates the influence of the cruciate ligaments on soft tissue balance throughout the range of flexion and thus identifies general aspects that must be considered during gap balanced TKA. Understanding the native soft tissue behavior as well as the loss of stability after cruciate ligament resection that needs to be compensated during TKA may help to improve knee prothesis designs and the according implant alignment to enhance patient satisfaction.

REFERENCES: 1. Dennis et al. 2010, 2. Kayani et al. 2019, 3. Ethical approval by the Ludwig Maximilian University of Munich (No. 20-0856)



a. b.

Fig. 1: a. Specimen with 3D fitted segmented CT scans containing landmark-based femoral and tibial coordinate systems. b. Exemplary measurement of the tibiofemoral gaps within the positioned CT scans.

a.

b.

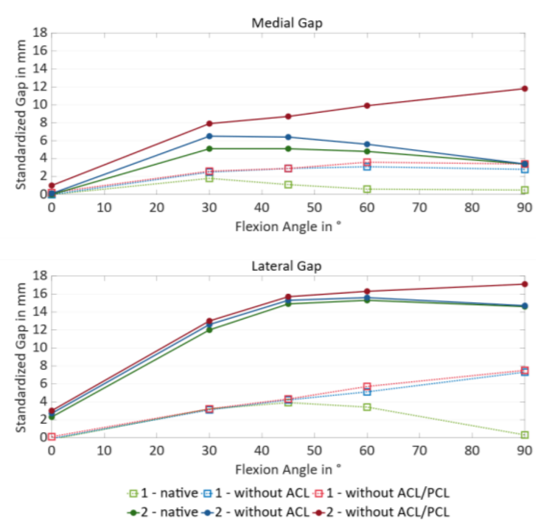


Fig. 2: Medial (a) and lateral (b) gaps throughout the range of flexion (0° to 90°) in the native knee (green), after ACL resection (blue) and after ACL + PCL resection (red) with one example each for group 1 (1) and group 2 (2).