The Q-angle and its effect on active kinematics – a simulation study

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Introduction: Currently, standard total knee arthroplasty (TKA) procedures focus on axial and rotational alignment of the prosthesis components and ligament balancing. Even though TKA has been constantly improved, e.g. by introducing navigation techniques, TKA patients still experience a significantly poorer functional outcome than total hip arthroplasty patients [1]. This suggests that other factors might have to be considered.

Among others, complications can occur when knee kinematics after TKA do not correspond with the physiological condition. Thereby it must be distinguished between active and passive motion [2]. We hypothesized that the quadriceps angle (Q-angle) has a substantial impact on active joint kinematics and should be taken into account in TKA implant positioning or even the patient specific adaptation of the prosthesis especially of the femoral component. The Q-angle according to [3] is defined as the angle between a first line from the anterior superior iliac spine to the center of the patella and a second line from the center of the patella to the tibial tuberosity (TT). Therefore, it can be influenced by the position of the TT.

A pathological position of the TT is commonly related to patellofemoral pain and knee instability [4]. A clinically well accepted surgical treatment is the TT medialization. In vitro studies indicate that medialization partially corrects abnormal contact pressures and adjusts patella maltracking [4]. The medialization causes a change in the orientation of the patella tendon and thus alters the biomechanics of the knee.

Consequently, patient specific medial/lateral TT position influences not only the patellofemoral but also tibiofemoral biomechanics. If active knee kinematics do not correspond to passive knee kinematics defined by the ligament situation, this aspect should be considered for implant design and positioning. Our goal was therefore to investigate the sensitivity of active knee kinematics related to the medial/lateral position of the TT (corresponding to a variation of the Q-angle) by using a complex multi-body model with a dynamic simulation of an entire gait cycle.

Material and Methods: The model has been implemented in the multi body simulation software AnyBody (AnyBody Technology A/S, Denmark). The model as published in [5] has been validated within the framework of the Grand Challenge Competition [6] and was adapted for the present issue. The knee joint is represented by articulating surfaces of a standard prosthesis and contains 6 degrees of freedom. A novel method called force-dependent kinematics was used for the calculations [5]. Intra-articular passive structures, such as collateral and cruciate ligaments are implemented. The muscular apparatus consists of 159 muscles per leg.

The joint coordinate system by Grood et al 1983 [7] was used to determine the tibiofemoral kinematics. Therefore, reference axes were identified based on anatomical landmarks on femur and tibia. The Q-angle was measured in a reference position (two leg stance).
As input parameter for the sensitivity analysis, the insertion point of the patella tendon was translated medially 9 mm and laterally 15 mm from the initial position in equidistant steps of 3 mm (fig A). Changes in tibiofemoral kinematics and Q-angle were recorded and compared with results of previous studies.

![Image A](image.png)

**Results and Discussion:** The Q-angle was about 10° in the initial position, which lies in the physiological range. It changed approximately 2.5° with a gradual shift of 3 mm, confirming the impact of the individual TT position on active knee kinematics. Depending on the position of the TT, the tibiofemoral kinematics, particularly the internal/external rotation of the tibia was significantly affected. Lateralization of the TT decreased the external rotation of the tibia with respect to the femur, whereas a medialization caused an increase of the external rotation (fig B). During contralateral toe off (CTO) the external rotation was +7.5° for a medial transfer of 9 mm and -1.4° for a lateral transfer of 15 mm, respectively.

The differences in external rotation were almost zero at the beginning, in the middle (30-40%) and at the end of the gait cycle. The evaluation of the activation pattern of the quadriceps muscle showed a correlation: the higher the activation of the quadriceps, the greater were the changes in kinematics (fig C). Consequently, no changes occurred during zero activation, which is the case for low flexion angles. Hence, the rotation depends on the loading condition, coinciding with the findings of Labey 2011 [8] that muscle action significantly changes knee kinematics.

In conclusion, knee kinematics are strongly affected by the Q-angle which is directly associated with the position of the TT. The activation of the quadriceps muscle plays a central role. As active kinematics may show significant differences to passive kinematics, intraoperative ligament balancing may result in a suboptimal ligament situation during active motion. Since the Q-angle varies widely between gender and
patients, the individual situation should be considered, e.g. in preoperative model based planning of patient specific TKA. The results should be verified in experimental studies and included in the analysis of further biomechanical parameters. Furthermore, the effects of different training stages of the quadriceps as well as the relative consequences for pre- and postoperative training and rehabilitation should be considered.

Limitations of this study were on the one hand the robustness of the model. In two cases no simulation results were obtained over the entire gait cycle. On the other hand, the model is only an approximation of the real physiological conditions. Its optimization and further experimental validation is one aspect of our ongoing work.

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