Optimizing Tibial Tubercle Positioning: A Key Strategy for Reducing Patellar Contact Pressure and Enhancing Knee Joint Stability

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INTRODUCTION:
The tibial tuberosity to trochlear groove (TT-TG) distance is a critical quantitative metric used to evaluate patellar instability. This measurement denotes the lateral offset between the tibial tuberosity (TT) and the trochlear groove (TG) of the femur. An increased TT-TG distance indicates a more laterally positioned tibial tuberosity, resulting in heightened lateral loading on the patella during knee movements, which may contribute to instability and discomfort. The surgical procedure known as tibial tubercle osteotomy (TTO) is commonly employed to ameliorate the TT-TG distance. However, there remains a substantial gap in the literature regarding the effects of alterations in TT-TG distance as a result of TTO. The objective of this study is to investigate the impact of changes in TT-TG distance on patellar contact pressure through the utilization of a detailed finite element mode of the knee.

METHODS:
The finite element (FE) simulations were performed using Abaqus 2025 (Dynamic/Explicit). The FE model was constructed based on an initial tibial tuberosity to TT-TG distance of 10 mm using TTO to determine the translation of the tibial tubercle. The tibial tubercle shifted in increments of 5 mm on the lateral and medial sides, respectively. The kinematics of the knee joint were defined by boundary conditions ranging from full extension (0°) to 90° flexion. It was validated using experimental data from previous studies. Bone, cartilage, and meniscus were modeled as linear elastic materials, while ligaments and tendons were represented as non-linear axial connector elements.

RESULTS:
The FE model of the knee joint was validated through prior research conducted in our laboratory. In this validated model, the average contact pressures recorded between the tibia and femur were 2.07 MPa on the lateral side and 2.11 MPa on the medial side. During the analysis of the gait cycle, particularly between 0 to 60° of knee flexion—a movement known to significantly affect the knee joint—it was observed that the contact pressure increased as the tibial tubercle shifted 10 mm away from its optimal position. This tendency was consistent for both lateral and medial translations. Within a defined range of TT-TG distances (from 0 to 10 mm), the contact pressures remained similar or even decreased compared to the initial position. Notably, as the TT-TG distance approached 0 mm at 90° of flexion, an increase in contact pressure was recorded. Conversely, beyond this specific range, a substantial increase in contact pressure (averaging 88%) was noted as the translation amount increased. This data supports the previously established optimal TT-TG distance. These findings suggest that carefully repositioning the tibial tubercle within this defined range through TTO may help decrease patellar contact pressure and enhance knee joint stability.

DISCUSSION:
This study demonstrated that patellofemoral contact pressure increases as the TT–TG distance deviates from the reference alignment, regardless of whether the translation is medial or lateral. Within a restricted range (0–10 mm), pressures were maintained at an appropriate level, suggesting that modest adjustments through TTO could be biomechanically acceptable. However, overcorrection, particularly toward a near-zero TT–TG distance, led to marked pressure increases at higher flexion angles, indicating the potential for cartilage overload and instability. These results align with clinical observations that excessive TT–TG values (>20 mm) are associated with patellar instability and confirm the importance of restoring, rather than minimizing, TT–TG during TTO. By quantifying the nearly 90% increase in joint stress outside the optimal range, this study provides biomechanical evidence supporting careful preoperative planning and intraoperative control. However, this study is limited in that it is preliminary and was conducted before biomechanical experiments. Further validation through cadaver experiments is required. In summary, when TTO was performed on the FE knee joint model, excessive TT-TG distance increased patella contact pressure. As a result, this study could present a reasonable range of TT-TG distances that could reduce patellar contact pressure and improve knee joint stability. This could suggest appropriate guidelines for performing TTO and provide insights for knee joint stabilization.

SIGNIFICANCE/CLINICAL RELEVANCE:
This study used FEA to reveal that TTO should restore the TT-TG distance to an optimal intermediate range, as both excessive medialization and lateralization increase the TT-TG distance. These findings could provide biomechanical guidance for improving knee stability in TTO.

REFERENCES:
[1] Wang Y et al. *J Orthop Surg Res*. 2020; [2] Yang et al. *Anthroscopy*. 2017; [3] Dandy DJ. *J Bone Joint Surg Br*. 1996; [4] Krishnan H et al. *Bone Jt Open*. 2022

IMAGES AND TABLES:

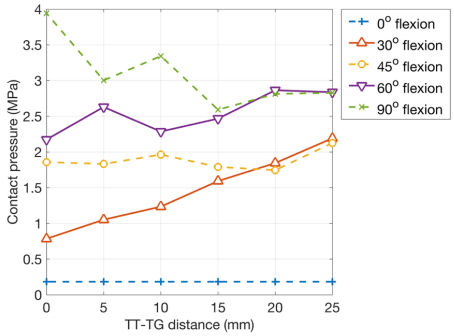

Fig. 1 Comparison of contact pressure depending on variations in TT-TG distance during the knee flexion