Relative impact of patellar under-resection versus weight loss on quadriceps force required for vertical thrust during stair-ascent after posterior stabilized total knee arthroplasty

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INTRODUCTION: Ability to ascend stairs without pain contributes to patients' satisfaction after total knee arthroplasty (TKA) [1]. Yet, 25% of patients one year after TKA express dissatisfaction due to pain and dysfunction during stair ascent [2]. One important mechanism dictating a patient's ability to successfully ascend stairs is the quadriceps force required to generate the extension moment at the 'vertical thrust' instance of this activity to overcome the flexion moment generated by the patient's body weight [3]. Therefore, weight loss can improve a patient's ability to successfully ascend stairs after TKA. In parallel, surgical parameters including under-resecting the patella during TKA installation can also enhance the extensor mechanism's effectiveness by increasing its lever arm during stair ascent. Unfortunately, how patellar under-resection affects a patient's ability to ascend stairs by modulating the required quadriceps forces compared to weight loss is poorly understood. Moreover, how under-resecting the patella impacts patellofemoral contact forces, which are associated with anterior knee pain, also remains unclear [4]. Therefore, we asked the following research question: How does under-resecting the patella impact the quadriceps force required during the vertical thrust instance of stair ascent and patellofemoral contact forces compared to weight loss?

METHODS: Computational models of ten independent cadaveric left knees (five males, five females; age: 63.7±10.5 years) were built by virtually implanting femoral, tibial and patellar components using a posterior-stabilized (PS) knee system (Persona, Zimmer-Biomet) (Fig. 1a). The tibiofemoral components were implanted using a previously published workflow [5]. This workflow included 26 nonlinear spring elements to represent the tibiofemoral soft tissue envelope, and slack lengths were calibrated to replicate their native tension in full extension as described previously [6]. Regarding installation of the patellar component, anatomical coordinates of the patella were first determined [7] to define a resection plane perpendicular to the anatomical anterior-posterior axis of the patella. Using this resection plane, bone was removed from the posterior aspect of the patella that was equivalent in thickness to the patellar component. The patellar component was then installed, resulting in an implanted patella with the same thickness as the native patella. Regarding the soft tissues constraining the patella, the medial and lateral patellofemoral ligaments and the patellar tendon were modeled with four and 20 nonlinear spring elements, respectively. Each tissues' insertion points were identified using bony landmark and previously published anatomical data (Fig. 1a) [8]. Their stiffness properties were obtained from previously published mean population data [9]. Slack lengths of the patellofemoral ligament and patellar tendon were set to their point-to-point distance at full extension. Next, we simulated the vertical thrust instance of stair ascent in three steps: First, the knee was passively flexed to 60° of flexion representing a flexion angle common at the vertical thrust instance of stair [2]. In the second step, we simulated the vertical thrust instant of stair ascent by applying subject-specific maximum flexion moment and ground reaction forces at 60° of flexion (Fig. 1b) [2]. The maximum flexion moment and ground reaction forces were obtained using mean values in the literature i.e. 3% body weight-height [2] and 1.1 body weight [3], respectively, and scaling by each specimen's body weight and height. In the third step, we applied the quadriceps force needed on the proximal patella and along the long axis of the femur. We performed this simulation process for the following three conditions: 1) reducing the patellar resection by 3 mm and subject-specific body weight; and 2) maintain the native patellar thickness with maximum flexion moment and ground reaction forces equivalent to 10% reduction in body weight. We chose 10% weight loss due to its feasibility within the healthy range of weight loss post TKA [10]. Outcome measures were quadriceps force required to generate the extension moment that equaled the maximum flexion moment and patellofemoral contact force both estimated at vertical thrust instance. For the research question, to compare required quadricep forces and patellofemoral contact forces between native patellar thickness, under resection, and weight loss, a Friedman test with Least Significant Difference post-hoc correction ($\alpha < 0.05$) was performed.

RESULTS SECTION: The quadriceps force required to generate extension moment equal to maximum flexion moment at vertical thrust instance of stair ascent decreased by 12.0% ($p<0.01$) and 15.5% ($p<0.001$) with patellar under-resection and 10% weight loss, respectively (Fig. 2). Additionally, under-resecting the patella increased patellofemoral contact force by 8% ($p<0.05$), while weight loss reduced the contact force by 12.5% ($p<0.05$) during the vertical thrust instance of stair-ascent (Fig. 3).

DISCUSSION: The key finding of this study was that under-resecting the patella by 3 mm can reduce the required quadriceps forces during the vertical thrust instance of stair ascent at the expense of increased patellofemoral contact forces, which is associated with anterior knee pain [4]. In contrast, weight loss can also improve the patient's ability for stair-ascent but with decreased patellofemoral contact forces. In conclusion, we developed a computational model to look at tradeoffs of surgical decisions and patient modifiable factors by showing this proof-of-concept study.

SIGNIFICANCE/CLINICAL RELEVANCE: We demonstrated that under-resecting the patella in TKA provides mechanical advantage for successful stair ascent, but it has the downside of increasing patellofemoral contact forces. In comparison, weight loss reduced the required quadriceps force more effectively without increasing patellofemoral contact forces.

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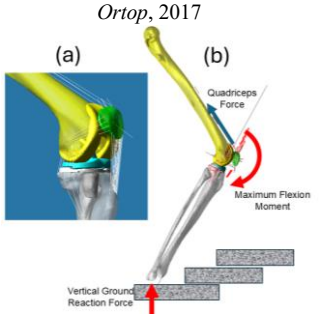

Figure 1: Computational modeling framework including a) tibio- and patello-femoral soft tissue and quadricep forces; b) simulating vertical thrust in stair-ascent after total knee arthroplasty

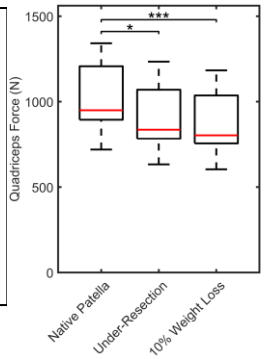

Figure 2: Boxplots of quadriceps forces required for vertical thrust in stair-ascent after total knee arthroplasty for patellar thickness equal to native patellar thickness, patellar under resection, and native thickness with 10% body weight loss. Red lines are medians and boxes are the interquartile ranges. The whiskers extend to the most extreme data points not considered outliers.

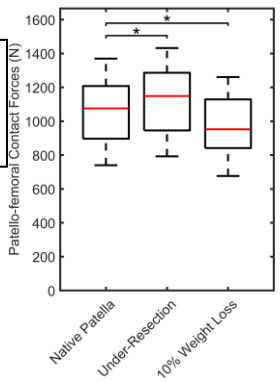

Figure 3: Boxplots of patellofemoral contact forces generated at vertical thrust in stair-ascent after total knee arthroplasty.