The effect of patellar thickness on gait biomechanics following total knee arthroplasty

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ABSTRACT

Background: Patella resurfacing is commonly performed during total knee arthroplasty; however, determining the appropriate patellar thickness remains a challenge. The purpose of this study was to evaluate the role of post-TKA patellar thickness on knee extensor strength and biomechanical joint loading forces during walking and stair negotiation.
Methods: Fifteen patients (21 knees) underwent gait analysis prior to TKA and post-TKA at six weeks, three months, six months, and one year. Knee extensor strength and biomechanics were collected during level walking and stair negotiation and analyzed using Pearson correlation coefficients.
Results: Knee extensor strength was positively correlated to patellar thickness at three months and one year post-TKA ($p \leq .05$). During walking, no significant correlations were present. During stair ascent, there was a positive correlation between patellar thickness and peak knee flexion angle one year post-TKA ($p \leq .05$). During stair descent, there was a positive correlation between patellar thickness and maximum vertical ground reaction forces at one year post-TKA ($p \leq .01$).
Conclusions: The loss of patellar thickness when compared to measured pre-resurfacing thickness was correlated with a decrease in knee extensor strength; however, changes in patellar thickness were not significantly correlated to biomechanical loading forces during walking. Increases in demand of activity increase the torque to the knee joint, which elicit increases in compensatory motions, likely reducing the extent to which differences in joint loading during stair negotiation may be attributable to changes in patellar thickness. Therefore, the effect of post-patellar thickness on patient function in primary TKA is limited.

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1. Introduction

Degenerative osteoarthritis (OA) commonly affects the articular surface of the patella and is the reason resurfacing was developed. Patella resurfacing, frequently performed during total knee arthroplasty (TKA), involves removing the articular surface of the patella and inserting a polyethylene button in order to provide a durable articular surface and to restore the patella to its original thickness. The objective of patella resurfacing during TKA is to relieve anterior knee pain and restore normal patellofemoral mechanics [1]. Unfortunately, resurfacing the patellofemoral joint is not without complications, which include polyethylene wear, fracture, and prosthetic loosening. In addition, previous research has reported a significant increase in patellofemoral pressure and changes in patellar kinematics following patellar resurfacing during TKA [2]. Based on these reported complications, preserving or restoring patellar structure has become a primary focus during TKA.

While reestablishing the original patellar thickness is recommended [1], preoperative patellar thickness is often not achieved following resurfacing during TKA, since replication of exact anatomy and a polyethylene button design of the native patella has not been perfected yet [3]. In vivo analysis has indicated that a patellar thickness of 11–15 mm or less may increase the risk for patellar fracture [4,5]. In addition to fracture, a postoperative patella that is too thin may also cause patellar maltracking and anterior knee pain [1]. Conversely, a resurfaced patella that is too thick has previously been reported to increase the risk of postoperative complications including subluxation [1,6], abnormal patellar tracking [1,6–8] and greater post-TKA patellar tilt [7]. Despite these clinical complications, it is still unclear if small differences in patellar thickness following TKA have a significant effect of postoperative function.

Compensatory gait patterns limiting the amount of knee flexion during walking, commonly referred to as "quadriceps gait", are often present in OA patients due to knee pain or weak knee extensor musculature [4,9]. Although previous research has described the relationship between a decrease in knee flexion angle and a decrease in patellar thickness, it is unclear if range of motion and function are sensitive to the small patellar thickness changes occurring during TKA [10]. Therefore, the purpose of this study was to evaluate the effect of changes in patellar thickness following TKA on knee extensor strength and sagittal plane knee biomechanical variables during walking gait and stair negotiation. It was hypothesized that patellar thickness would be positively correlated to knee extensor strength, range of motion and joint loading during both walking and stair negotiation.

2. Materials and methods

This longitudinal gait study included 15 patients (21 knees) undergoing TKA for the treatment of OA, with gait analysis occurring prior to TKA and at six weeks, three months, six months and one year post-TKA. Of the 21 total knees included in this study, nine were unilateral TKAs and six were simultaneous bilateral TKAs. For unilateral patients, the extent of OA was not evaluated in the contralateral limb. However, the senior surgeon in the current study frequently performs simultaneous bilateral TKAs. Therefore, if OA was present in the contralateral limb in these patients, it had not yet progressed to cause pain or functional deficits. Inclusionary criteria included: 1) under 75 years of age, 2) no previous history of lower extremity fracture, osteotomy, or joint replacement, 3) undergoing a unilateral or bilateral TKA for the treatment of OA, and 4) able to walk without an aid. The same board certified orthopedic surgeon performed all TKA procedures, including patellar resurfacing for this study and all patients signed informed consent forms approved by the Institution's Committee on Human Studies. Patients were randomly allocated to receive either a single-radius implant (GetAroundKnee™, Stryker Orthopedics, Mahway, NJ) or a Multi-radius implant (Balanced Knee® System, Ortho Development Corporation, Draper, UT).

During TKA, patients underwent a standard medial parapatellar approach and the TKA was performed with standard instrumentation as provided by the implant system. All patellar cuts were made free-hand with a standard oscillating saw without the aid of patellar cutting instrumentation. Patellar cut was accepted after the surgeon determined that the patellar cut was symmetrical regarding inferior/superior patellar thickness and medial/lateral patellar thickness by palpation. Patellar thickness measurements were acquired during surgery using standard calipers to measure the thickness before and after resurfacing.

All biomechanical analyses were conducted at the University Gait Laboratory. Walking gait and stair negotiation biomechanics were collected using 29 retroreflective markers placed on bony landmarks. These landmarks were located on the thorax (including the xiphoid process, jugular notch, cervical vertebrae seven, thoracic vertebrae ten, apex of the scapular and bilaterally on the acromioclavicular joints), the pelvis (including bilaterally on the anterior superior iliac spine and posterior superior iliac spine) and lower extremities (including bilaterally on the head of the first metatarsal, head of the second metatarsal, head of the fifth metatarsal, base of the fifth metatarsal, calcanei, medial malleolus, lateral malleolus, medial femoral epicondyle, lateral femoral epicondyle). Additionally, four marker arrays were secured bilaterally on the thigh and shank segments. It is important to note that the markers located bilaterally on the head of the first metatarsal, medial malleolus and medial femoral epicondyle were used only for the static calibration capture and were removed for the data collection process. A photo with the location of the marker placement used for motion capture during the data collection process can be found in Figure 1. Kinematic data were collected with a Vicon motion capture system and Vicon Nexus software (Vicon, Inc., Centennial, CO) at 240 Hz and time synchronized with kinetic data. Kinetic data from the involved limb were collected at 960 Hz from two force plates (Advanced Mechanical Technology Incorporated, Boston, MA), one embedded flush with the floor and one instrumented within the second step of the stairs. All kinematic data were smoothed using a low-pass Butterworth filter with a 10 Hz cut-off and ground reaction forces were filtered using a 50 Hz cut-off frequency. External joint moments were calculated using inverse dynamics based on marker

Figure 1. Location of markers used during motion capture for gait analysis.

trajectories and kinetic data which were filtered using a 10 Hz cut-off frequency [11]. All data was processed using Visual 3D (C-Motion, Inc., Germantown, MD).

Walking gait data were collected barefoot at self-selected velocity for each participant. A successful walking trial required placement of the entire foot on the force plate without a visible change in gait in an attempt to target the force plate. Participants performed the minimum number of trials necessary to obtain three acceptable trials for the involved limb undergoing TKA. Stair negotiation trials followed a similar protocol performed by Vallabhajosula et al. [12]. Patients were instructed to walk up the stairs "as quickly and as safely as possible." Each patient was asked to take two additional steps on the stair platform to ensure that a natural gait was continued through the last step and deceleration did not occur. For stair descent, patients took a step on the stair platform prior to stepping down onto the force plate with the involved limb. An additional three steps were taken after completion of the stair descent trials. Handrails were provided for safety but patients were instructed not to use them unless balance was compromised. If the handrails were used, the trial was discarded and not included for data analysis. Due to high intra-subject variability previously reported during stair climbing in the OA population, five successful trials were averaged [12].

Following stair descent trials, strength tests were conducted using a MicroFET2 hand held dynamometer (Hoggan Health Industries, West Jordan, UT) and performed in a gravity dependent position. Knee extensor strength was assessed while the patient was seated with the knee placed at 60° of knee flexion and their trunk in a recumbent position, flexed 50° from the surface of the table. The hand held dynamometer was placed on the anterior shank, at a point 80% of the distance from the lateral knee joint

Table 1
Participant demographics (n = 13, 19 knees).

	Mean	±	SD
Anthropometrics			
Age (yrs)	66.2	±	5.2
Body Mass (kg)	77.3	±	10.2
Height (m)	1.7	±	0.7
BMI	28.1	±	3.4
Patellar thickness (mm)			
Pre-TKA patellar thickness	22.5	±	2.0
Post-TKA patellar thickness	20.7	±	1.8
Delta	−1.8	±	1.2
Walking velocity (m/s)			
Pre-TKA	0.98	±	0.2
3 months post-TKA	1.05	±	0.16
6 months post-TKA	1.12	±	0.11
1 year post-TKA	1.06	±	0.13

n = number, SD = standard deviation, kg = kilograms,
m = meters, BMI = body mass index, mm = millimeters,
TKA = total knee arthroplasty, m/s = meters per second

line to the lateral malleolus, and secured with a strap. The dynamometer was fixed to the lower tibia to increase the validity and reliability of the measure [13] and is a recommended alternative technique to the isokinetic dynamometer for evaluating hip and knee strength [14]. Participants were instructed to build force over three seconds, holding the maximal contraction force for two seconds. Two trials of a three-second maximal effort were completed. A third trial was completed if the second trial did not measure within 10% force output of the first trial. Verbal encouragement was provided to help elicit maximal force production by the participant during strength testing.

2.1. Statistical analysis

The maximal force produced during strength testing trials was used for analysis. Biomechanical gait parameters evaluated in this study included peak knee flexion angle (PKFA), joint loading as indicated by peak knee flexion moment (PKFM) and maximum vertical ground reaction force (vGRF) during walking and stair ascent trials. Analysis of stair descent included vGRF as well as peak knee flexion angle (PKFA_25) and peak knee flexion moment (PKFM_25) produced during the first 25% of the stance phase while stepping down onto the force plate and loading the knee joint.

Data were log transformed in order to standardize the heterogenous ranges of measurement between the biomechanical variables and patellar thickness. Log transformed data were used for all comparisons between post-TKA patellar thickness and post-TKA biomechanical variables of interest. Pearson correlation coefficients were performed to evaluate the relationship between post-patellar thickness and the log-transformed biomechanical variables of interest. Statistical analyses were conducted using SPSS version 23.0 (IMB, Armonk, NY, USA). All joint moments reported are external. Post-hoc power analysis revealed power of 0.80 for the group size of 19 knees in this study for correlations of $r \geq 0.456$ and an alpha level of $p < .05$.

3. Results

Two patients were removed from data analysis, one due to a crouched walking gait and the other for missing two of the three post-TKA data collections, resulting in 13 patients (19 knees) being utilized for data analysis. Due to the limited number of TKA

Table 2
Mean walking gait biomechanical variables, knee extensor strength and correlation coefficient.

	Pre-TKA (n = 19 knees)	3 months post-TKA (n = 16 knees)			6 months post-TKA (n = 19 knees)			1 year post-TKA (n = 16 knees)		
	Mean ± SD	Mean ± SD	Correlation	p-Value	Mean ± SD	Correlation	p-Value	Mean ± SD	Correlation	p-Value
PKFA (°)	22.02 ± 9.46	20.69 ± 6.23	−0.064	0.814	20.19 ± 5.56	−0.001	0.998	19.48 ± 4.29	−0.011	0.970
PKFM (Nm/kg)	0.59 ± 0.31	0.62 ± 0.23	−0.144	0.595	0.68 ± 0.23	0.061	0.803	0.64 ± 0.26	−0.016	0.956
vGRF (N/kg)	10.15 ± 0.67	10.15 ± 0.45	−0.189	0.483	10.36 ± 0.80	−0.240	0.323	10.10 ± 0.59	−0.212	0.447
Knee Extensor Strength (pounds)	66.8 ± 27.5	56.6 ± 14.3	0.547*	**0.019**	64.0 ± 21.0	0.336	0.090	65.0 ± 24.6	0.526*	**0.034**

TKA = total knee arthroplasty, n = number, SD = standard deviation, PKFA = peak knee flexion angle, ° = degrees, PKFM = peak knee flexion moment, Nm/kg = New meters per kilogram, vGRF = vertical ground reaction force, N/kg = newton per kilogram, * = significantly correlated at $p < .05$, **bold** = significant p-Value.

Table 3
Mean stair ascent biomechanical variables and correlation coefficient.

	Pre-TKA	3 months post-TKA			6 months post-TKA			1 year post-TKA		
	(n = 19 knees)	(n = 18 knees)			(n = 18 knees)			(n = 15 knees)		
	Mean ± SD	Mean ± SD	Correlation	p-Value	Mean ± SD	Correlation	p-Value	Mean ± SD	Correlation	p-Value
PKFA (°)	70.69 ± 5.95	67.18 ± 4.34	−0.061	0.822	66.79 ± 16.24	−0.011	0.964	63.72 ± 22.78	0.589*	**0.027**
PKFM (Nm/kg)	0.61 ± 0.31	0.64 ± 0.66	−0.108	0.692	0.57 ± 0.24	−0.254	0.309	0.6 ± 0.23	−0.253	0.383
vGRF (N/kg)	10.60 ± 0.72	10.53 ± 0.72	0.105	0.711	11.03 ± 2.59	−0.307	0.884	10.61 ± 2.82	0.091	0.756

TKA = total knee arthroplasty, n = number, SD = standard deviation, PKFA = peak knee flexion angle, ° = degrees, PKFM = peak knee flexion moment, Nm/kg = New meters per kilogram, vGRF = vertical ground reaction force, N/kg = newton per kilogram, * = significantly correlated at p < .05, **bold** = significant p-Value.

patients able to perform stair negotiation at six weeks postoperatively, data from this data collection period were not included for analysis. Descriptive statistics for all participant demographics and walking velocity measurements are reported in Table 1. Descriptive statistics for knee extensor strength and all biomechanical variables of interest are reported in Table 2 (walking), Table 3 (stair ascent) and Table 4 (stair descent). The pre- to post-TKA patellar thickness was strongly, positively correlated (r = 0.818, p < .001).

Despite significant correlations between post-TKA patellar thickness and knee extensor strength at three months and one year, significant correlations between post-TKA patellar thickness and biomechanical variables were limited. Knee extensor strength (Table 2) was significantly correlated to post-TKA patellar thickness at both three months (r = 0.491, p ≤ .05) and at one year (r = 0.526, p ≤ .05) with a trend toward a significant correlation at six months (r = 0.336, p = .09). However, during walking gait, no significant correlations were present between post-patellar thickness and PKFA, PKFM or vGRF at any of the post-TKA data collection time periods (Table 2). During stair ascent (Table 3), patellar thickness and PKFA were significantly positively correlated (r = 0.589, p ≤ .05) at one year post-TKA. During stair descent (Table 4), a significant negative correlation was found between patellar thickness and vGRF (r = −0.658, p ≤ .01) at one year post-TKA.

4. Discussion

The most important finding of this study was that patellar thickness following TKA was not associated with changes in biomechanical joint loading variables during walking. When more demanding tasks were performed, including strength measurements and stair negotiation, a few significant correlations between patellar thickness and outcome variables were present. However, the prevalence of compensatory motions during demanding tasks following TKA [15,16] and the lack of consistency in these correlations across time points during stair negotiation in the present study, makes precise interpretation of these biomechanical changes difficult.

Despite the initial hypothesis that patellar thickness and joint loading would be positively correlated during walking, the lack of correlation in this study is not surprising. The ability to walk on a level surface following TKA is a reasonably simple task with minimal muscle strength required, producing insignificant compensatory motions compared to much more demanding tasks, such as negotiating stairs [15,17]. However, the positive correlation between patellar thickness and knee extensor strength following TKA in the current study suggests that a more demanding task may produce more apparent loading difference due to patellar thickness.

In the current study, patellar thickness was significantly correlated with PKFA during stair ascent and vGRF during stair decent. Both of these variables represent a patients' ability to load the joint, suggesting a lack of strength or balance in the surgical leg. However, previous research has reported that challenging activities, such as stair negotiation, increase the amount of mechanical compensations [16], which likely explains the lack of consistence over time in the current study. Additionally, functional deficits and compensatory motions have previously been reported to remain after one year [15], limiting the extent to which the relationship between changes in patellar thickness and joint loading during demanding tasks can be understood.

Table 4
Mean stair descent biomechanical variables and correlation coefficient.

	Pre-TKA	3 Month			6 Month			1 Year		
	(n = 19 knees)	(n = 16 knees)			(n = 19 knees)			(n = 14 knees)		
	Mean ± SD	Mean ± SD	Correlation	P-value	Mean ± SD	Correlation	P-value	Mean ± SD	Correlation	P-value
PKFA_25 (°)	27.35 ± 10.33	25.27 ± 5.84	−0.169	0.564	26.84 ± 7.92	−0.225	0.301	27.46 ± 4.42	−0.193	0.527
PKFM_25 (Nm/kg)	0.80 ± 0.41	0.82 ± 0.26	0.172	0.556	0.93 ± 0.33	0.278	0.508	0.95 ± 0.27	0.238	0.435
vGRF (N/kg)	13.57 ± 4.27	13.56 ± 2.32	−0.200	0.492	14.72 ± 3.91	−0.244	0.355	13.95 ± 1.41	−0.658§	**0.014**

TKA = total knee arthroplasty, n = number, SD = standard deviation, PKFA_25 = peak knee flexion angle during first 25% stance, ° = degrees, PKFM_25 = peak knee flexion moment during first 25% stance, Nm/kg = newton meters per kilogram, vGRF = vertical ground reaction force, N/kg = newton per kilogram, § = significantly correlated at p < .01, **bold** = significant p-Value.

Results of this study demonstrate the limited effect of patellar thickness on post-operative biomechanical variables, which could be related to limitations of this study. Sample sizes could have been larger, increasing the effect size of this study. Additionally, there was a limited relative change in actual patellar thickness size following resurfacing which may have had an impact on results. Further, non-standardization of rehabilitation programs may have constituted a limitation in the present study. However, the rehabilitation protocols for all TKA patients were based on direction from the same board certified physician with the aim of the rehabilitation being to recover patient range of motion.

5. Conclusion

The results of the current study indicate that maintenance of the native patellar thickness serves to improve knee extensor strength, which may suggest improved patient function post-TKA. However, the lack of correlation between post-patellar thickness and biomechanical joint loading during walking may indicate that, despite some decrease in knee extension strength related to decreased post-patellar thickness, these changes were not great enough to prevent normal function during walking gait. As the demands of functional activities increase, such as in stair negotiation, post-patellar thickness may become a more important consideration relative to overall function, though the precise effect is unclear since increased compensatory motions are present. Therefore, according to this study, as long as the patellar resurfacing thickness is within two millimeters of the native patellar thickness, and the patellar thickness remains above the fracture risk threshold of 11–15 mm [4,5,8], the effect of post-patellar thickness on function following TKA is likely to be limited.

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