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Fracture Risk With Patella Resurfacing During Total Knee Arthroplasty After Anterior Cruciate Ligament Reconstruction Using Bone-Patella-Bone Autograft: A Biomechanical Analysis

J. Heath Wilder, MD, Akshar H. Patel, MD, Bailey J. Ross, BA, John M. Weldy, MD, Hao Wang, William F. Sherman, MD, MBA *

Department of Orthopaedic Surgery, Tulane University School of Medicine, New Orleans, LA, USA

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ABSTRACT

Background: Anterior cruciate ligament (ACL) tears are common injuries. Ipsilateral bone patellar tendon bone (BPTB) autograft has been frequently used for ACL reconstructions. A large percentage of patients who sustain ACL ruptures develop early osteoarthritis and require total knee arthroplasty (TKA). When patients with previous BPTB autograft for an ACL tear undergo TKA, there may be an increased risk of fracture after patellar resurfacing.
Methods: There were 20 artificial Sawbones and 10 cadaveric patellae resurfaced. To simulate the presence of a previous BPTB autograft, a bone plug was removed from the anterior surface of the patellae and was resurfaced with a cemented patellar button. Biomechanical testing was performed to determine the compressive load to fracture of patellae with and without previous BPTB autograft.
Results: The average maximum load to failure for the artificial Sawbones patellae without a previous BPTB autograft was 4551.40 N ± 753.12 compared with 2855.39 N ± 531.46 with a previous BPTB autograft ($P < .001$). The average maximum load to failure for the cadaveric patellae without a previous BPTB autograft was 7256.37 N ± 1473.97 compared with 5232.22 N ± 475.04 with a previous BPTB autograft ($P = .021$).
Conclusions: The results demonstrate a significantly lower maximum load to failure of a resurfaced patella in the presence of a previous BPTB autograft. This can be used to aid in the decision of whether to resurface the patellae in these patients and to educate patients that the presence of a previous BPTB autograft may be an increased risk factor for patella fracture after TKA.
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Introduction

Anterior cruciate ligament (ACL) tears are one of the most common injuries presenting to orthopedic surgeons with an annual incidence of 68.6 to 80 per 100,000 person-years [1,2]. As the rate of ACL tears continues to increase, the rate of ACL reconstruction (ACLR) has also significantly increased 22% from 2002 to 2014 [3]. There are multiple autograft options for ACLR including hamstring tendon autograft, quadriceps tendon autograft, and bone patellar tendon bone (BPTB) autograft. Originally described in 1963, the BPTB autograft involves removing the central third of the patellar tendon as well as bone plug from the tibial cortex and a bone plug from the patella in the ipsilateral knee as the ACL injury [4,5]. The BPTB continues to be a preferred autograft for high-level athletes with excellent functional outcomes, low recurrence rates, and high rates of return to sport [4,6]. Although the success rate of BPTB autograft is high, patellar fractures after ACLR with a BPTB graft have been reported at an incidence of 0.2% to 1.8% [7-10].

Total knee arthroplasty (TKA) is also one of the most performed procedures for osteoarthritis of the knee with over 700,000 performed annually and models projecting an increase in TKA to over 3.4 million procedures by the year 2030 in the United States alone [11,12]. Patellar complications account for about 10% of all TKA

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* Corresponding author. 1430 Tulane Avenue, New Orleans, LA 70112, USA. Tel.: +1 504 982 0252.

E-mail address: swilliam1@tulane.edu

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complications and remain a source of poor outcomes after TKA [13,14]. Complications of TKA involving the patella include avascular necrosis, fractures, and loosening [15,16]. Periprosthetic fractures of the patella have been reported in 0.2% to 21% of cases when patellar resurfacing is performed [17-20]. Canton et al. reported resurfacing of the patella has been associated with 99% of periprosthetic patellar fractures after TKA [20]. When the native patella is not resurfaced during TKA, the incidence of a patellar fracture has been reported at 0.05% [17]. Waters and Bentley reported patellar resurfacing was associated with anterior knee pain in 5.3% of patients compared with the 25.1% of patients in the nonresurfacing group [21]. However, Barrack et al. performed a prospective, randomized double-blind trial demonstrating retention of the native patella during a TKA procedure which yielded clinical results that were comparable to those with patellar resurfacing although 10% of these needed subsequent resurfacing [22]. In addition, Abdel et al. demonstrated 90% of orthopedic surgeons in North America routinely resurface the patella during a TKA procedure [23].

The data on routine use of patella resurfacing during TKA are controversial. With continued growth of patients undergoing TKA because of post-traumatic osteoarthritis from ACL tears [24], the purpose of this study was to compare whether a resurfaced patella during TKA conferred equal strength in terms of maximum load to patellar fracture in the presence and absence of a previous BPTB autograft. We hypothesize the maximum load to failure of a cemented resurfaced patella in the presence of a previous BPTB autograft will be less than that in the absence of a previous BPTB autograft as measured by biomechanical testing of artificial and cadaveric patellae.

Material and methods

Institutional review board exemption was granted (IRB#2021-1264). This study used a 3-peg, symmetric, all polyethylene, cemented patella implant from the Stryker Triathlon system (Stryker Ltd., Kalamazoo, MI) measuring 9 mm in height × 33 mm in diameter for all patellae. Measurements taken before mechanical testing included the anterior-posterior (AP) depth of each patella before resurfacing, after resurfacing, and with the final button implant in addition to the maximum medial-lateral (ML) pole width and maximum superior-inferior (SI) pole length.

Artificial Sawbones model preparation

Twenty, large fourth-generation composite patellae with a homogenous density of 17 pounds per cubic feet at 0.27g/cm^3 (SKU 3419, Pacific Research Laboratories, Vashon, WA) were selected to best represent the patella of a patient diagnosed with osteoarthritis undergoing TKA [25]. The dimensions of the Sawbones patellae had an AP depth of 24.93 mm before resurfacing, a length of 45.65 mm from SI pole, and a ML width of 50 mm at the widest point (Table 1). While these models are prepared in a way that ensures consistency, calipers were used to validate the dimensions. These dimensions are comparable to human patellae that have an average AP depth of 23.9 mm in males and 21.8 mm in females, an average SI length of 45.6 mm in males and 40.0 mm in females, and an average ML width of 46.6 mm in males and 41.7 mm in females [26,27]. A Stryker System 8 oscillating saw (Stryker Ltd., Kalamazoo, MI) was used to resurface the patella by removing an average of 10.53 ± 0.82 mm from the articular surface of each artificial Sawbones patellae to achieve a surface appropriate for resurfacing, leaving a remaining average thickness of 14.40 ± 0.82 mm. To harvest the BPTB autograft, the technique described by Frank et al. was used, which results in a 20- to 25-mm long, 10-mm wide, and 6- to 7-mm deep bone plug from the patella. The saw blade was oriented approximately 30° toward the midline when harvesting on either side of the plug and aimed 45° obliquely toward either of the longitudinal cuts to ultimately create a trapezoidal patellar bone plug [4] (Fig. 1a). After removal of the BTPB autograft plug, the average resection amount was measured at 7.55 mm from the thickest point of the patella in the AP dimension to the bottom of the graft harvest site. Using the same system designated drill bit and guide (Stryker Ltd., Kalamazoo, MI), three 6.35-mm holes were drilled into the cut surface, which are arranged in a symmetric triangular pattern representative of the configuration of the patella placed in the everted surgical position. All patellae were implanted with a 9 × 33-mm polyethylene, symmetric patella button using Stryker Simplex HV cement (Stryker Ltd., Kalamazoo, MI) (Fig. 1b). Each

Table 1
The measurements of all artificial Sawbones patellae in millimeters with and without prior harvest of bone patellar tendon bone site.

Trial	AP depth after resurface	AP depth after button placement	SI length (max)	ML width (max)	Trough to cut	Material lost
Cemented composite patellae without prior BPTB autograft						
No BPTB 1	15.73	24.10	48.76	50.10	N/A	N/A
No BPTB 2	15.41	23.90	47.56	50.65	N/A	N/A
No BPTB 3	14.20	22.40	42.40	50.60	N/A	N/A
No BPTB 4	14.59	23.21	44.31	50.39	N/A	N/A
No BPTB 5	13.57	21.92	40.23	50.18	N/A	N/A
No BPTB 6	14.16	21.98	47.22	49.50	N/A	N/A
No BPTB 7	13.90	22.37	40.98	49.85	N/A	N/A
No BPTB 8	14.15	22.53	42.31	50.18	N/A	N/A
No BPTB 9	12.98	22.04	37.92	49.84	N/A	N/A
No BPTB 10	14.80	22.89	42.66	49.91	N/A	N/A
Cemented composite patellae with prior BPTB autograft						
BPTB 1	14.50	22.89	45.47	49.96	6.52	7.98
BPTB 2	14.92	22.63	48.58	50.21	7.11	7.81
BPTB 3	14.11	22.19	44.23	50.12	7.49	6.62
BPTB 4	13.94	22.56	43.18	49.57	6.10	7.84
BPTB 5	12.63	21.71	40.50	50.11	5.24	7.39
BPTB 6	15.13	22.62	47.82	50.18	7.58	7.55
BPTB 7	14.52	23.59	45.56	50.07	7.13	7.39
BPTB 8	14.77	23.79	47.14	50.10	7.11	7.66
BPTB 9	14.10	23.31	44.98	50.14	7.12	6.98
BPTB 10	15.83	23.05	49.10	50.08	7.52	8.31

AP, anterior posterior; BPTB, bone patellar tendon bone; ML, medial lateral; SI, superior inferior.
Of note, the AP depth of all artificial Sawbones patellae was 24.93 mm before resurfacing.

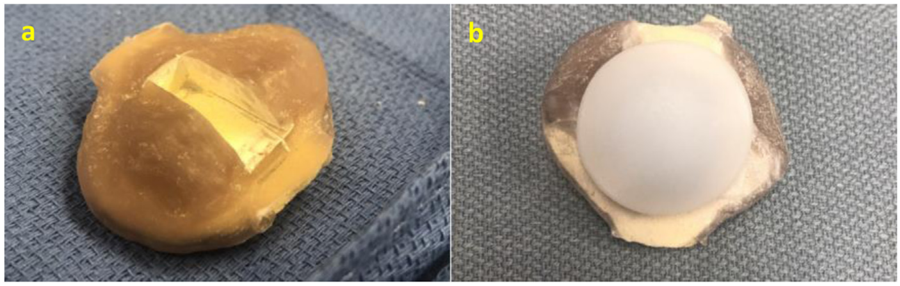

Figure 1. (a) Resurfaced artificial Sawbones patella after bone patellar tendon bone site was harvested (7.55 mm anterior-posterior depth, 10 mm width, 25 mm length removed from anterior-inferior portion of patella) using the technique described by Frank et al. [4]. (b) Posterior view of symmetric, poly-ethylene button cemented onto artificial Sawbones patella after resurfacing with an average anterior-posterior depth of 22.78 ± 0.69 mm.

patella button was centered on the patella to provide the best circumferential fit.

Cadaveric patellae preparation

Five pairs of matched cadaveric patellae were obtained from Science Care (Phoenix, AZ) including 1 male and 4 female donors (age range 69-96 years, mean 80.0 ± 10.3 years). Each patella was visually inspected to ensure the bone quality was adequate and consistent with its matched pair. Before resurfacing, the average AP depth for all ten patellae was 22.49 mm, an average SI length of 39.93 mm, and an average ML width of 43.17 mm (Table 2). Using the same method during the artificial Sawbones preparation, an oscillating saw was used to resurface the patella by removing an average of 8.22 ± 1.37 mm from the articular surface of each cadaveric patellae to achieve a surface appropriate for resurfacing leaving a remaining thickness of 14.27 ± 2.51mm. Using the same technique described by Frank et al., a BPTB autograft plug was resected from one patella of each matched pair with an average of 6.60 mm from the thickest point to the bottom of the graft harvest site [4] (Fig. 2a). Using the system-designated drill bit and guide, three 6.35-mm holes were drilled into the cut surface, which are arranged in a symmetric triangular pattern representative of the configuration of the patella placed in the everted surgical position. All patellae were implanted with a 9 × 33-mm polyethylene, symmetric button using the same cement as the artificial Sawbones patellae (Fig. 2b). Each patella button was centered on the patella to provide the best circumferential fit.

Biomechanical testing

A biaxial servohydraulic testing machine (MTS Bionix 370; MTS Systems Corporation, Eden Prairie, MN) was used to test the maximum load to patellar fracture of each patella with the cemented patellar button implant in the absence and presence of a BPTB autograft harvest site. The anterior cortical area of each construct was mounted onto the stationary load cell of the MTS Test System. The actuator was attached to a compression plate and used to load the button on the posterior side of the patella (Fig. 3). Room temperature was controlled at 22°C. The construct was first preloaded to 100 N and held under that load for 90 seconds to achieve a steady viscoelastic state, define zero-strain at a set preload, and ensure uniform contact with the compression plate [28]. The compression plate attached to the actuator descended at a rate of 5 mm/s in axial compression until ultimate load to failure representing a patella fracture occurred [29]. Fractures of the patella were identified by 2 methods: a decrease in strength in the stress-strain curve noted on the MTS followed by visual inspection to confirm fracture (Fig. 4). For each specimen, the MTS Test System recorded the ultimate force and displacement required to achieve fracture. To adjust for varying AP depths of patellae produced during patellar resurfacing, ultimate force per 1-mm AP depth was calculated for each specimen.

Statistical analysis

A statistical analysis was performed using Microsoft Excel (Microsoft Corporation, Redmond, WA) with the XLSTAT statistical package add-on (Addinsoft Inc., New York, NY) with an α level set to 0.05. To evaluate the observed differences in artificial Sawbones patellae specimens, a 2-tailed independent sample student's t-test was performed to quantify the differences in average maximum compressive force (or maximum load to failure as represented by a periprosthetic patellar fracture), average displacement, and the maximum force per 1 mm of AP depth. For the cadaveric patellae, a 2-tailed paired t-test was performed to evaluate the same parameters between matched pairs of cadaveric patellae in the presence and absence of a previous BPTB autograft. All data were reported as mean ± standard deviation.

Table 2
The measurements of all cadaveric bone patellae in millimeters with and without prior harvest of bone patellar tendon bone site.

Trial	AP depth before resurface	AP depth after resurface	AP depth after button placement	SI length (max)	ML width (max)	Trough to cut	Material lost
Cemented cadaveric patellae without prior BPTB autograft							
No BPTB 1	22.97	14.29	23.52	37.33	45.70	N/A	N/A
No BPTB 2	22.10	11.86	20.12	37.74	40.19	N/A	N/A
No BPTB 3	21.85	14.28	22.10	39.20	40.38	N/A	N/A
No BPTB 4	27.14	19.64	28.16	47.14	48.47	N/A	N/A
No BPTB 5	19.21	12.90	21.46	36.86	43.10	N/A	N/A
Cemented cadaveric patellae with prior BPTB autograft							
BPTB 1	23.21	14.01	22.62	38.87	48.28	8.68	5.33
BPTB 2	21.57	12.38	20.48	36.82	38.86	6.97	5.41
BPTB 3	20.01	14.09	22.12	40.12	40.31	7.28	6.81
BPTB 4	26.56	17.50	25.50	45.17	40.78	9.76	7.74
BPTB 5	20.29	11.79	20.91	40.07	45.67	5.68	6.11

AP, anterior posterior; BPTB, bone patellar tendon bone; ML, medial lateral; SI, superior inferior.

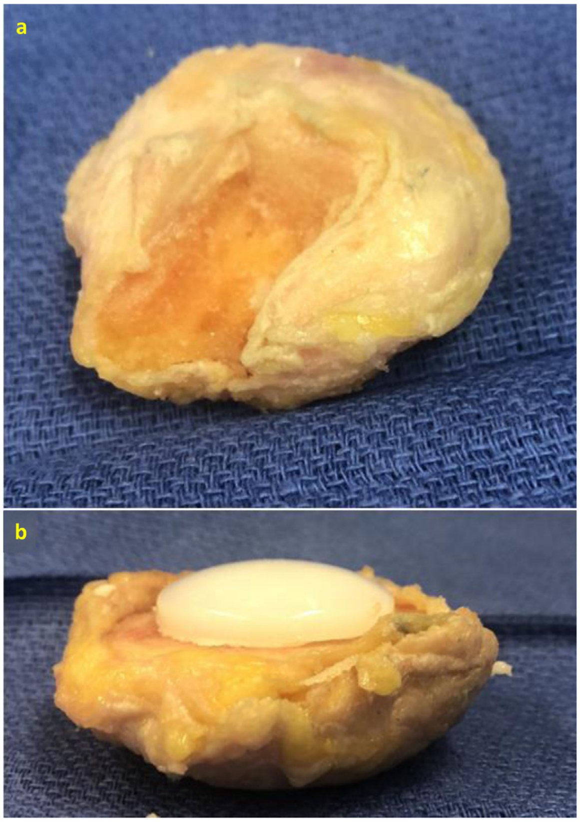

Figure 2. (a) Resurfaced cadaveric patella after bone patellar tendon bone site was harvested (6.60 mm anterior-posterior depth, 10 mm width, 25 mm length removed from anterior-inferior portion of patella) using the technique described by Frank et al. [4]. (b) Side view of resurfaced cadaveric patella after placement of cemented, symmetric poly-ethylene button with an average anterior-posterior depth of 22.69 ± 2.48 mm.

Results

Artificial Sawbones patellae

For the artificial Sawbones patellae, the final average AP depth with the button cemented and placed was 22.78 ± 0.69 mm for both the patellae with and without a previous BPTB autograft. With the patellar button in place, the average AP depth of the artificial Sawbones patellae without the BPTB harvest was 22.73 ± 0.78 mm while the average AP depth of the patellae with the prior BPTB harvest was 22.83 ± 0.63 mm. The average AP depth of the BPTB harvest site to the cemented button was 14.87 ± 1.09 mm. The average maximum load to fracture for the artificial Sawbones patellae in the absence of a previous BPTB autograft was 4551.40 N ± 753.12 N with 3.21 ± 0.97 mm of displacement compared with 2855.39 N ± 531.46 N with 3.29 ± 0.47 mm of displacement for the patellae with a previous BPTB autograft ($P < .001$) (Table 3 and 4). In the artificial Sawbones model, the fracture pattern was less uniform. While several patellae fractured in a transverse fashion, many were also comminuted as well. There was no significant difference in the displacement required to cause a periprosthetic patellar fracture in the presence or absence of a previous BTPB autograft ($P = .809$). However, when accounting for the differences in AP depth between artificial Sawbones patellae, the maximum force eliciting fracture per 1 mm of AP depth in absence of a previous BPTB autograft was significantly higher at 200.37 N ± 33.72 N than 125.08 N ± 23.17 N for patellae with a prior BPTB autograft ($P < .001$).

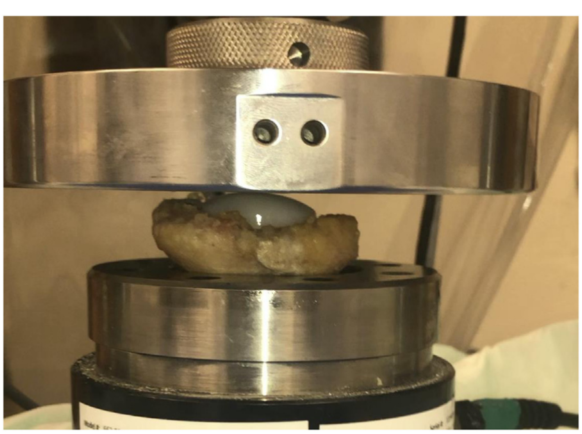

Figure 3. Compression plate attached to the actuator descending at a rate of 5 mm/s in axial compression until ultimate load to failure representing a patella fracture occurred.

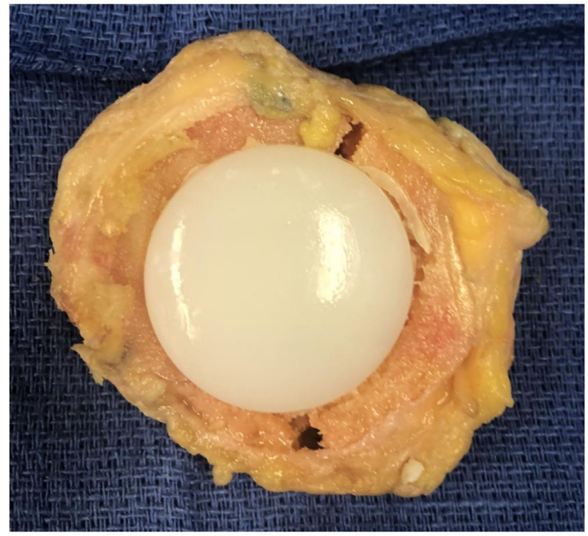

Figure 4. After MTS testing and recording of displacement and the force required to cause fracture, the maximum load to failure represented by a peri-prosthetic patellar fracture was observed.

Cadaveric patellae

For the cadaveric patellae, the final average AP depth with the patella button cemented and placed was 22.69 ± 2.48 mm for both the patellae with and without a previous BPTB autograft. With the patellar button in place, the average AP depth of the artificial Sawbones patellae without the BPTB harvest was 23.07 ± 3.10 mm, while the average AP depth of the patellae with the prior BPTB harvest was 22.33 ± 1.96 mm. The average AP depth of the BPTB harvest site to the button was 16.58 ± 1.10 mm. The average maximum load to fracture for the cadaveric patellae in the absence of a previous BPTB autograft was 7256.37 N ± 1473.97 N with 7.17 ± 1.44 mm of displacement compared with 5232.22 N ± 475.04 N with 6.44 ± 0.87 mm of displacement for patellae with a previous BPTB autograft ($P = .021$) (Table 5 and 6). In the cadaveric specimens, most patellae fractured in a transverse pattern in both the patellae with and without a BPTB autograft. There was no significant difference in the displacement required to cause a periprosthetic patellar fracture in the presence and absence of a previous BTPB autograft ($P = .297$). When accounting for the

Table 3
Biomechanical testing results of artificial Sawbones patellae with and without prior harvest of bone patellar tendon bone site.

Trial	Max compressive force (N)	Max displacement (mm)
Cemented composite patellae without prior BPTB autograft		
No BPTB 1	4979.82	4.13
No BPTB 2	4630.66	4.27
No BPTB 3	5355.99	5.13
No BPTB 4	3186.05	2.23
No BPTB 5	4890.27	2.60
No BPTB 6	4700.50	2.41
No BPTB 7	4492.76	3.00
No BPTB 8	5199.07	3.13
No BPTB 9	3227.36	2.55
No BPTB 10	4851.58	2.68
Cemented composite patellae with prior BPTB autograft		
BPTB 1	1882.48	2.17
BPTB 2	2532.18	3.03
BPTB 3	3395.31	3.76
BPTB 4	2676.62	3.36
BPTB 5	2973.79	3.22
BPTB 6	2360.65	3.38
BPTB 7	3492.30	3.09
BPTB 8	2906.14	3.66
BPTB 9	2775.93	3.44
BPTB 10	3558.41	3.81

BPTB, bone patellar tendon bone.

difference in AP depth between cadaveric patellae, the mean maximum force eliciting fracture per 1 mm of AP depth was significantly higher at 317.48 N ± 67.54 N for patellae without a prior BPTB autograft compared with 235.58 N ± 27.82 N in the presence of a prior BPTB autograft ($P = .027$).

Discussion

The risks associated with patella resurfacing during TKA in patients with prior ACLR using BPTB autograft are unclear. This study demonstrates a significant difference in the maximum load to failure, represented by a periprosthetic patellar fracture, between resurfaced patellae in the presence and absence of a previous BPTB autograft by 59.4% in the artificial Sawbones patellae and 38.7% in cadaveric patellae ($P < .001$ and $P = .021$, respectively).

The history of a previous knee surgery has been documented to correlate with the need for TKA at a much younger age compared to patients with no history of knee surgery (59 ± 10 years vs 66.6 ± 10.4 years); more specifically, patients with a history of ligament reconstruction are at higher risk for TKA at an even younger age than patients with a history of other knee surgery (50.2 ± 9.1 years vs 59.9 ± 9.6 years) [30]. While most ACL tears and ACLRs occur among younger cohorts, it has been previously reported that 16% to 65.5% of these ACL tears progress to osteoarthritis of the ipsilateral knee after ACLR for this injury [31]. In addition, most patients that suffer from osteoarthritis secondary to knee ligament injury have onset of symptoms 10-20 years earlier than patients with primary osteoarthritis [32,33]. Regardless of whether operative treatment is performed for an ACL tear, Ajuied et al. reported a relative risk of 3.89 for developing any osteoarthritis and a relative risk of 3.84 for developing moderate to severe osteoarthritis at a mean 10-year follow-up [34]. Furthermore, Leroux et al. demonstrated patients with previous ACLR were at 7 times greater odds to receive a TKA than matched control patients from the general population after 15 years (1.4% and 0.2%, respectively) [24].

The utilization of the BPTB autograft has become more prevalent over the past few decades because of relative ease of harvest, strength of tissue, and bone-to-bone healing with secure fixation [35]. Tibor et al. reported a total of 5123 BPTB autografts used for ACLR with a stable incidence ratio from 2007 to 2014 [36]. Donor site pain is a common side effect when BPTB autograft is used for ACLR because of slow or inadequate bone buildup in the harvest sites [37]. After the BPTB harvest, the patella becomes weaker with the bone plug removed and the disruption of blood supply [38]. Simonian et al. also reported alterations in the mechanical strain experienced by the patella after bone harvest [39]. The combination of bone loss and altered mechanical strain leaves the patella vulnerable to fracture and additional complications. Furthermore, at an average follow-up duration of 13.5 years after ACLR with BPTB autograft, Struewer et al. reported 73.8% of patients evaluated using the Kellgren and Lawrence score had radiographical evidence of grade I or II osteoarthritis, and the prevalence of grade III or IV osteoarthritis was 20% despite a high degree of patient satisfaction and good clinical results [40].

There are several limitations to this study. As the artificial Sawbones patellae are designed to represent native, human patellae, there are inherent and noticeable differences with respect to composition and density in comparison to human patellae. To address the differences observed in the artificial Sawbones patellae, cadaveric patellae were obtained and tested using identical

Table 4
Average maximum force (N), maximum displacement (mm), and maximum force per 1 mm AP depth for artificial Sawbones patellae with and without prior harvest of bone patellar tendon bone site.

Mean value	BPTB	No BPTB	*P* value
Average max compressive force (N) ± SD	2855.38 ± 531.46	4551.40 ± 753.12	.00002
Average max displacement (mm) ± SD	3.29 ± 0.47	3.21 ± 0.97	.80938
Max force per 1 mm AP depth ± SD	125.08 ± 23.17	200.37 ± 33.72	.00002

BPTB, bone patellar tendon bone; SD, standard deviation.
Corresponding *P* values denote significance.

Table 5
Biomechanical testing results of cadaveric bone patellae with and without prior harvest of bone patellar tendon bone site.

Trial	Max compressive force (N)	Max displacement (mm)
Cemented cadaveric patellae without prior BPTB autograft		
No BPTB 1	9765.07	6.06
No BPTB 2	7171.12	6.18
No BPTB 3	6355.80	6.24
No BPTB 4	6952.59	8.14
No BPTB 5	6037.27	9.24
Cemented cadaveric patellae with prior BPTB autograft		
BPTB 1	5642.86	5.38
BPTB 2	5499.12	6.66
BPTB 3	4446.84	6.21
BPTB 4	5427.83	7.76
BPTB 5	5144.45	6.18

BPTB, bone patellar tendon bone.

Table 6
Average maximum force (N), maximum displacement (mm), and maximum force per 1 mm AP depth for cadaveric bone patellae with and without prior harvest of bone patellar tendon bone site.

Mean value	BPTB	No BPTB	*P* value
Average max compressive force (N) ± SD	5232.22 ± 475.04	7256.37 ± 1473.97	.02130
Average max displacement (mm) ± SD	6.44 ± 0.87	7.17 ± 1.44	.29678
Max force per 1 mm AP depth ± SD	235.58 ± 27.82	317.48 ± 67.54	.02705

BPTB, bone patellar tendon bone; SD, standard deviation.
Corresponding *P* values denote significance.

resurfacing and BPTB autograft-removal techniques, with one orthopedic surgeon trained in adult reconstruction performing all techniques. There was also a large difference in the ultimate load to patella fracture between the artificial Sawbones patellae and the cadaveric patellae with and without a BPTB harvest. Given this difference, one may expect to find variable in vivo results where the ultimate load to patellar fracture may be closer to the cadaveric specimens from the present study. There is no standardized technique to resurface the patella during a TKA procedure to ensure the resurfaced patella is a standardized AP depth before placing a cemented button [41]. Similar to the operating room, the lack of standardization introduces variability in the depth of patellae resurfaced for this study. To account for the variability of AP depth in the resurfaced patellae, we performed additional statistical analyses to assess the maximum force per 1 mm of depth of each patella. To further decrease variability in this study, all patellae were resurfaced and cemented with materials from one manufacturer, and results may vary with other manufacturers and designs. In addition, the uniform, progressive load used by the MTS machine in this study does not replicate all the possibilities of a periprosthetic patellar fracture in vivo with the knee in various positions with varying forces. A final limitation is the bone harvest site would be at its weakest point immediately after harvest, and one could expect some level of cancellous bone ingrowth in this defect along with fibrous tissue that may confer added stability such that it is possible that the large decrease in strength could be mitigated with some bone regeneration in younger patients. Therefore, given that the present analysis illustrated time zero failure, the demonstrated significant differences in strength may not persist in cases of remote harvesting, and future research is warranted.

With this knowledge, surgeons may also be able to predict the amount of bridge between a previous BPTB autograft harvest and the resected articular cartilage to effectively mitigate the additional risk of patellar fracture after TKA. Intraoperative images may be of utility in bridge assessment before patellar resurfacing via a merchant view or even a CT scan, which has been gaining popularity in routine TKA with the implementation of robotics.

Conclusion

Orthopedic surgeons encounter an increasing number of patients with post-traumatic osteoarthritis secondary to ACL tears necessitating TKA, many of whom were treated with a BPTB autograft. The results present in this study demonstrate a significantly lower maximum load to failure of a resurfaced, cemented patella in the presence of a previous BPTB autograft. For surgeons who are selective with regard to patella resurfacing, these data can be useful to aid in this decision, and patients can be educated that a previous BPTB autograft may be an increased risk factor for patella fracture after TKA.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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References

[1] Sanders TL, Maradit KH, Bryan AJ, et al. Incidence of anterior cruciate ligament tears and reconstruction: a 21-year population-based study. Am J Sports Med 2016;44(6):1502.
[2] Frobell RB, Lohmander LS, Roos HP. Acute rotational trauma to the knee: poor agreement between clinical assessment and magnetic resonance imaging findings. Scand J Med Sci Sports 2007;17(2):109.
[3] Herzog MM, Marshall SW, Lund JL, Pate V, Mack CD, Spang JT. Trends in incidence of ACL reconstruction and concomitant procedures among commercially insured individuals in the United States, 2002-2014. Sports Health 2018;10(6):523.
[4] Frank RM, Higgins J, Bernardoni E, et al. Anterior cruciate ligament reconstruction basics: bone-patellar tendon-bone autograft harvest. Arthrosc Tech 2017;6(4):e1189.
[5] Jones KG. Reconstruction of the anterior cruciate ligament. A technique using the central one-third of the patellar ligament. J Bone Joint Surg Am 1963;45:925.
[6] West RV, Harner CD. Graft selection in anterior cruciate ligament reconstruction. J Am Acad Orthop Surg 2005;13(3):197.
[7] Tay GH, Warrier SK, Marquis G. Indirect patella fractures following ACL reconstruction: a review. Acta Orthop 2006;77(3):494.
[8] Berg EE. Management of patella fractures associated with central third bone-patella tendon-bone autograft ACL reconstructions. Arthroscopy 1996;12(6):756.
[9] Christen B, Jakob RP. Fractures associated with patellar ligament grafts in cruciate ligament surgery. J Bone Joint Surg Br 1992;74(4):617.
[10] Viola R, Vianello R. Three cases of patella fracture in 1,320 anterior cruciate ligament reconstructions with bone-patellar tendon-bone autograft. Arthroscopy 1999;15(1):93.
[11] Kurtz S, Ong K, Lau E, Mowat F, Halpern M. Projections of primary and revision hip and knee arthroplasty in the United States from 2005 to 2030. J Bone Joint Surg Am 2007;89(4):780.
[12] Inacio MCS, Paxton EW, Graves SE, Namba RS, Nemes S. Projected increase in total knee arthroplasty in the United States - an alternative projection model. Osteoarthritis Cartilage 2017;25(11):1797.
[13] Putman S, Boureau F, Girard J, Migaud H, Pasquier G. Patellar complications after total knee arthroplasty. Orthop Traumatol Surg Res 2019;105(1S):S43.
[14] Maheshwari AV, Tsailas PG, Ranawat AS, Ranawat CS. How to address the patella in revision total knee arthroplasty. Knee 2009;16(2):92.
[15] Brick GW, Scott RD. Blood supply to the patella. Significance in total knee arthroplasty. J Arthroplasty 1989;4(Suppl):S75.
[16] Matz J, Lanting BA, Howard JL. Understanding the patellofemoral joint in total knee arthroplasty. Can J Surg 2019;62(1):57.
[17] Goldberg VM, Figgie HE, Inglis AE, et al. Patellar fracture type and prognosis in condylar total knee arthroplasty. Clin Orthop Relat Res 1988;236:115.
[18] Parvizi J, Jain N, Schmidt AH. Periprosthetic knee fractures. J Orthop Trauma 2008;22(9):663.
[19] Windsor RE, Scuderi GR, Insall JN. Patellar fractures in total knee arthroplasty. J Arthroplasty 1989;4(Suppl):S63.
[20] Canton G, Ratti C, Fattori R, Hoxhaj B, Murena L. Periprosthetic knee fractures. A review of epidemiology, risk factors, diagnosis, management and outcome. Acta Biomed 2017;88(2S):118.
[21] Waters TS, Bentley G. Patellar resurfacing in total knee arthroplasty. A prospective, randomized study. J Bone Joint Surg Am 2003;85(2):212.
[22] Barrack RL, Wolfe MW, Waldman DA, Milicic M, Bertot AJ, Myers L. Resurfacing of the patella in total knee arthroplasty. A prospective, randomized, double-blind study. J Bone Joint Surg Am 1997;79(8):1121.
[23] Abdel MP, Parratte S, Budhiparama NC. The patella in total knee arthroplasty: to resurface or not is the question,. Curr Rev Musculoskelet Med 2014;7(2):117.
[24] Leroux T, Ogilvie-Harris D, Dwyer T, et al. The risk of knee arthroplasty following cruciate ligament reconstruction: a population-based matched cohort study. J Bone Joint Surg Am 2014;96(1):2.
[25] Burnett W, Kontulainen S, McLennan C, et al. Patella bone density is lower in knee osteoarthritis patients experiencing moderate-to-severe pain at rest. J Musculoskelet Neuronal Interact 2016;16(1):33.
[26] Baldwin JL, House CK. Anatomic dimensions of the patella measured during total knee arthroplasty. J Arthroplasty 2005;20(2):250.
[27] Yoo JH, Yi SR, Kim JH. The geometry of patella and patellar tendon measured on knee MRI. Surg Radiol Anat 2007;29(8):623.
[28] Zhao S, Arnold M, Ma S, et al. Standardizing compression testing for measuring the stiffness of human bone. Bone Joint Res 2018;7(8):524.
[29] Beck CM, Nwannunu BI, Teigen KJ, Wagner RA. Biomechanical study of patellar component fixation with varying degrees of bone loss. J Arthroplasty 2021;36(2):739.
[30] Brophy RH, Gray BL, Nunley RM, Barrack RL, Clohisy JC. Total knee arthroplasty after previous knee surgery: expected interval and the effect on patient age. J Bone Joint Surg Am 2014;96(10):801.
[31] Curado J, Hulet C, Hardy P, et al. Very long-term osteoarthritis rate after anterior cruciate ligament reconstruction: 182 cases with 22-year' follow-up. Orthop Traumatol Surg Res 2020;106(3):459.
[32] Ferretti A, Conteduca F, De Carli A, Fontana M, Mariani PP. Osteoarthritis of the knee after ACL reconstruction. Int Orthop 1991;15(4):367.
[33] Roos H, Adalberth T, Dahlberg L, Lohmander LS. Osteoarthritis of the knee after injury to the anterior cruciate ligament or meniscus: the influence of time and age. Osteoarthritis Cartilage 1995;3(4):261.

[34] Ajuied A, Wong F, Smith C, et al. Anterior cruciate ligament injury and radiologic progression of knee osteoarthritis: a systematic review and meta-analysis. Am J Sports Med 2014;42(9):2242.
[35] Reinhardt KR, Hetsroni I, Marx RG. Graft selection for anterior cruciate ligament reconstruction: a level I systematic review comparing failure rates and functional outcomes. Orthop Clin North Am 2010;41(2):249.
[36] Tibor L, Chan PH, Funahashi TT, Wyatt R, Maletis GB, Inacio MC. Surgical technique trends in primary ACL reconstruction from 2007 to 2014. J Bone Joint Surg Am 2016;98(13):1079.
[37] Schandl K, Horváthy DB, Doros A, et al. Bone-Albumin filling decreases donor site morbidity and enhances bone formation after anterior cruciate ligament reconstruction with bone-patellar tendon-bone autografts. Int Orthop 2016;40(10):2097.
[38] Piva SR, Childs JD, Klucinec BM, Irrgang JJ, Almeida GJ, Fitzgerald GK. Patella fracture during rehabilitation after bone-patellar tendon-bone anterior cruciate ligament reconstruction: 2 case reports. J Orthop Sports Phys Ther 2009;39(4):278.
[39] Simonian PT, Mann FA, Mandt PR. Indirect forces and patella fracture after anterior cruciate ligament reconstruction with the patellar ligament. Case report. Am J Knee Surg 1995;8(2):60. discussion 64-5.
[40] Struewer J, Frangen TM, Ishaque B, et al. Knee function and prevalence of osteoarthritis after isolated anterior cruciate ligament reconstruction using bone-patellar tendon-bone graft: long-term follow-up. Int Orthop 2012;36(1):171.
[41] Barrack RL, Wolfe MW. Patellar resurfacing in total knee arthroplasty. J Am Acad Orthop Surg 2000;8(2):75.