Original research

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

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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

No author associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work. For full disclosure statements refer to https://doi.org/10.1016/j.artd.2021.10.011.

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https://doi.org/10.1016/j.artd.2021.10.011

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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 9% 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 99% of periprosthetic patellar necrosis, fractures, and loosening [15,16]. Periprosthetic fractures of the patella have been reported in 0.2% to 21% of cases when patellar resurfacing [22]. In addition, Abdel et al. demonstrated the TKA procedure which yielded clinical results that were comparable to those with patellar resurfacings 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 failure of the native patella during a TKA [23].


table 1

| Trial | Cemented composite patellae without prior BPTB autograft | Cemented composite patellae with prior BPTB autograft |
|-------|----------------------------------------------------------|------------------------------------------------------|
| No BPTB 1 | 15.73 | 14.50 |
| No BPTB 2 | 15.41 | 15.40 |
| No BPTB 3 | 14.20 | 13.97 |
| No BPTB 4 | 14.59 | 14.46 |
| No BPTB 5 | 13.57 | 13.45 |
| No BPTB 6 | 14.16 | 13.90 |
| No BPTB 7 | 13.90 | 13.90 |
| No BPTB 8 | 14.15 | 14.15 |
| No BPTB 9 | 12.98 | 12.98 |
| No BPTB 10 | 14.80 | 14.80 |

Materials 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 foot at 0.27g/cm³ (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 BPTB 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
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 arti

**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**

| 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 |
|-------|---------------------------|--------------------------|---------------------------------|-----------------|---------------|--------------|--------------|
| 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          |
| 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           | 40.76         | 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.
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 BPTB 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 ($P < .001$).

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 22.69 ± 2.48 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 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 BPTB autograft ($P = .297$). When accounting for the
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 ± 27.82 N in the presence of a prior BPTB autograft compared with 235.58 N ± 2855.38 N in the absence of a prior BPTB autograft (P = .027).

### Discussion

The risks associated with patella resurfacing during TKA in patients with prior ACLR using BPTB autografts are unclear. This study demonstrates a significant difference in the maximum load to failure, represented by a periprosthetic patellar fracture, between patients with prior ACLR using BPTB autograft and those without a previous ACLR. 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.[2] 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] 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 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 who 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]

### 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 patella 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 patella 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                  |

### 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 | .000002 |
| 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 | .000002 |

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 patella 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 patella 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 peri-prosthetic 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 osteoarthrosis 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.

Acknowledgment

The authors would like to thank Rita A. Richardson for her technical support.

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