



## Original research

## Patella Strength Characteristics in Cemented vs Press-fit Implants: A Biomechanical Analysis of Initial Stability

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## ABSTRACT

**Background:** Patellar resurfacing is routinely performed during total knee arthroplasty to reduce pain associated with patellofemoral osteoarthritis. With 3-dimensional ingrowth materials readily available, the present study aimed to evaluate if cemented polyethylene (CP) patellar buttons conferred higher ultimate load to failure than press-fit metal-backed (PF) buttons in axial compression.

**Material and methods:** Ten matched cadaveric and 20 composite patellae were resurfaced and implanted with either a PF or CP button. Biomechanical testing using an MTS machine was performed to measure the force required to generate a periprosthetic patella fracture. Mean load to failure and load to failure per 1-mm patellar thickness were compared with a paired and independent samples Students' t-test for the cadaveric and composite patellae, respectively.

**Results:** The average load to failure for the matched cadaveric patellae with PF implants was significantly lower than that for patellae with CP buttons (4082.05 N vs 5898.37 N,  $P = .045$ ). The average load to failure for composite patella with PF implants was significantly higher than that for composite patellae with CP implants (6004.09 N vs 4551.40 N,  $P = .001$ ). The mean load to failure per 1-mm patellar thickness was also significantly higher for composite patellae with PF implants (263.80 N/mm vs 200.37 N/mm,  $P = .001$ ).

**Conclusion:** Cadaveric patellae with cemented implants had a significantly higher ultimate load to failure in axial compression than press-fit patella. However, this result was reversed in the composite model. Exploration of biological and composite model properties could provide further insight into patellar implant selection during total knee arthroplasty.

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## Introduction

With greater than 90% survivorship at 15 years, total knee arthroplasty (TKA) is a highly successful procedure, and volume is projected to increase 85% for primary cases and 78%–182% for revision cases by the year 2030 in the United States [1–4]. Patients undergoing TKA often have positive clinical and functional outcomes as patient satisfaction is reported at 70% to 93% [5–8]. Due to

the advancements in technology, TKA continues to improve with the advent of new implant designs, materials, cutting guides, imaging-based surgical planning, patient-specific implants, computer navigation, and robotics [9–14].

Although routine use remains controversial, patella resurfacing is often performed during TKA to remove cartilage from the patellofemoral joint and reduce pain [15]. Indications for resurfacing the patella include patients with inflammatory arthropathy, deformity, anterior knee pain, patella maltracking, and patellar subluxation [16–18]. Patella resurfacing is, however, associated with complications including osteonecrosis, implant loosening, fragmentation, and postoperative fractures [19]. With a growing popularity of press-fit femoral and tibial components for TKA [20],

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**Table 1**

The measurements of all composite bone patellae in millimeters with a cemented Stryker X3 polyethylene implant and with a press-fitted Stryker Tritanium metal-backed implant.

Stryker X3 polyethylene implant cemented on composite patellae				
Trial	AP depth after resurface	AP depth after button placement	SI length (max)	ML width (max)
Cemented 1	15.73	24.10	48.76	50.10
Cemented 2	15.41	23.90	47.56	50.65
Cemented 3	14.20	22.40	42.40	50.60
Cemented 4	14.59	23.21	44.31	50.39
Cemented 5	13.57	21.92	40.23	50.18
Cemented 6	14.16	21.98	47.22	49.50
Cemented 7	13.90	22.37	40.98	49.85
Cemented 8	14.15	22.53	42.31	50.18
Cemented 9	12.98	22.04	37.92	49.80
Cemented 10	14.80	22.89	42.66	49.91
Stryker Tritanium metal-backed implant press-fitted on composite patellae				
Trial	AP depth after resurface	AP depth after button placement	SI length (max)	ML width (max)
Press-fit 1	11.61	20.46	45.72	50.60
Press-fit 2	15.40	23.96	48.15	49.76
Press-fit 3	15.30	23.86	50.56	50.33
Press-fit 4	11.65	20.78	39.80	49.78
Press-fit 5	15.50	24.10	48.33	50.42
Press-fit 6	15.96	24.86	51.52	50.23
Press-fit 7	14.25	22.83	41.75	50.11
Press-fit 8	12.96	21.75	47.57	49.93
Press-fit 9	15.04	23.98	47.82	50.13
Press-fit 10	12.31	21.13	41.28	49.68

All measurements are in millimeters.

Of note, the average AP depth of all composite bone patellae was 24.93 mm prior to resurfacing.

press-fit implants have also been introduced for patellae resurfacing [21].

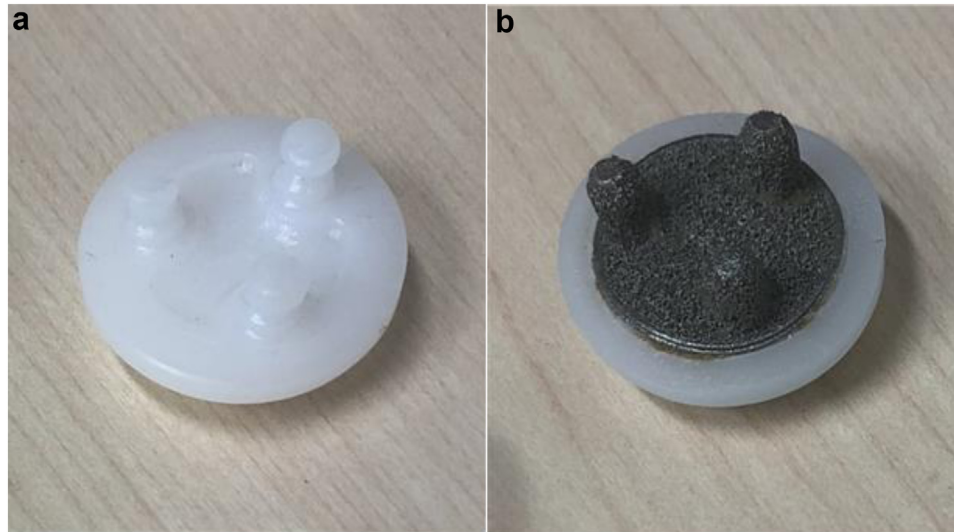
The majority of patellae resurfacing are currently performed with cemented all-polyethylene buttons as metal-backed patellae have been historically reported to have increased complications [22,23]. However, with 3-dimensional ingrowth materials becoming more readily available, there has been an increase in utilization of press-fit patella implants. With time, these implants help in cancellous cross-linking of bony trabeculae to the porous ingrowth materials. The present study aimed to evaluate if cemented polyethylene patella buttons conferred a greater initial strength in terms of a higher ultimate load to failure than press-fit patella buttons in axial compression representing a direct fall. It was hypothesized that the addition of cement to the subchondral bone would lead to a higher ultimate load to failure than for patellae with a press-fit button after initial fixation.

## Material and methods

After obtaining approval from the institutional review board (IRB#2021-056), 2 types of patella button implants from the Stryker Triathlon system (Stryker Ltd., Kalamazoo, MI) were investigated: the cemented polyethylene X3 patella, and the press-fit Tritanium Metal-Backed patella. Each patella button implant had a three-peg configuration, was symmetric, and measured 9 mm in height  $\times$  33 mm in diameter as seen in Figure 1. Measurements taken prior to mechanical testing of all patellae included the anterior-posterior (AP) depth before cutting the patella, after cutting the patella, and after final implantation of the patella button. In addition, the maximum medial-lateral (ML) pole width and maximum superior-inferior (SI) pole length were recorded (Tables 1 and 2).

## Composite bone model preparation

Twenty, large, fourth-generation composite patellae with a density of 17 pounds per cubic feet (SKU 3419; Pacific Research Laboratories, Vashon, WA) were used to simulate fracture testing during a fall or direct blow. Each composite patella had a homogeneous density of 0.27 g/cm<sup>3</sup> and was selected to best represent the patella of a patient diagnosed with osteoarthritis who is undergoing TKA [24]. The dimensions of the composite patellae prior to resurfacing measured on average 24.93 mm by 44.84 mm by 50.11 mm in terms of AP depth by SI length by maximum ML width. These composite measurements were comparable and consistent with the reported in vivo dimensions of human patellae, with males, on average, having an AP depth of 23.9 mm by SI length of 45.6 mm by ML width of 46.6 mm and females, on average, having an AP depth of 21.8 mm by SI length of 40.0 mm by ML width of 41.7 mm [25,26]. Each patella in the study was resurfaced by removing an average of 10.76 mm of bone from the articular side with a Stryker System 8 oscillating saw (Stryker Ltd., Kalamazoo, MI), which left an average thickness of 14.17 mm. Using the system-designated drill bit and guide (Stryker Ltd., Kalamazoo, MI), the cut surface of each patella was drilled to form three 6.35-mm holes arranged in a symmetric triangular pattern, a configuration representative of an everted patella during surgery. Subsequently, of the 10 total composite patellae, 5 were implanted with a symmetric, 9  $\times$  33 mm press-fit Tritanium metal-backed patella button, and the remaining 5 were implanted with a symmetric, 9  $\times$  33 mm polyethylene patella button using Stryker Simplex HV cement (Stryker Ltd., Kalamazoo, MI). To achieve complete cement polymerization, each polyethylene implanted composite patella was allowed to cure for 20 minutes prior to biomechanical testing [27]. All measurements of composite patellae prior to and after resection of the articular surface in addition to depth restoration with the implanted buttons are provided in Table 1.



**Figure 1.** Patella button implants from the Stryker Triathlon system (Stryker Ltd., Kalamazoo, MI). A side-by-side comparison showing (a) a Stryker X3 polyethylene implant and (b) a Stryker Tritanium metal-backed implant.

#### Cadaveric specimen preparation

Cadavers were screened and selected to include those with no history of musculoskeletal disease, defects, or previous surgeries. The specimens were obtained from Science Care (Phoenix, AZ). Five pairs of matched cadaveric patellae were procured from 3 male and 2 female donors (age range 66–90 years, mean  $81.6 \pm 9.8$  years) as seen in Figure 2. Each patella was inspected for consistency with its matched pair in terms of size and shape and to confirm there was no evidence of pathology or fracture. Additionally, manual examination was subjectively used to estimate that cancellous bone quality was adequate for implantation based on the experience of one adult reconstruction fellowship-trained orthopedic surgeon. Prior to resurfacing, all 10 cadaveric patellae averaged an AP depth of 24.29 mm, SI length of 47.38 mm, and ML width of 45.11 mm. The cadaveric patellae were resurfaced with an oscillating saw using the same method as in the composite bone preparation. An average of 9.78 mm was removed from the articular surface of each cadaveric patellae to achieve a uniform surface with an average remaining thickness of 14.50 mm. Using the same designated drill

bit and guide system, three 6.35-mm holes, arranged in a symmetric triangular pattern, were drilled into the cut surface. After preparation of bony surfaces, each left cadaveric patella was implanted with a symmetric,  $9 \times 33$  mm polyethylene patella button using Stryker Simplex HV cement, and each right patella was implanted with a symmetric,  $9 \times 33$  mm press-fit Tritanium metal-backed patella button. To achieve complete cement polymerization, each polyethylene implanted cadaveric patella was allowed to curate for 20 minutes prior to biomechanical testing. All measurements of cadaveric patellae prior to and after resection of the articular surface in addition to depth restoration with the implanted buttons are provided in Table 2.

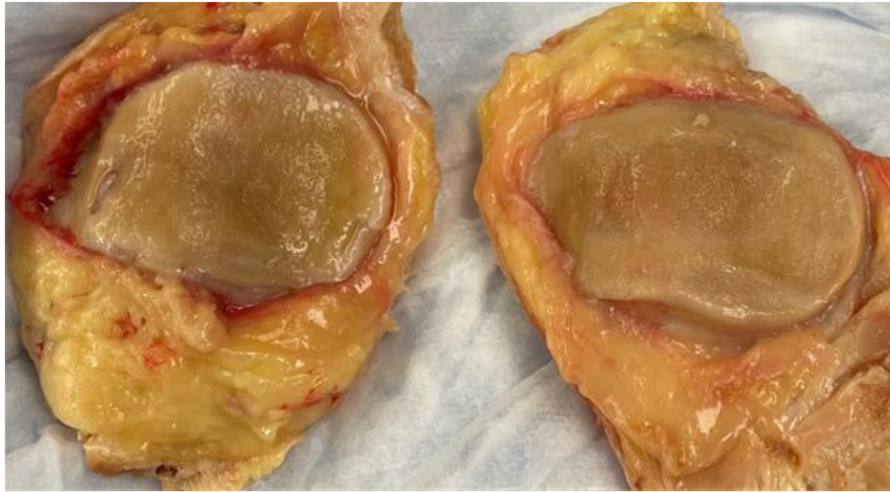
#### Biomechanical testing

A biaxial servohydraulic testing machine (MTS Bionix 370; MTS Systems Corporation, Eden Prairie, MN) was used to test the maximum load to failure of each patella with a cemented button implant and each patella with a press-fit button implant. Room temperature was controlled at 22°C. The anterior cortical area of

**Table 2**  
The measurements of all matched cadaveric bone patellae in millimeters with a cemented Stryker X3 polyethylene implant and with a press-fitted Stryker Tritanium metal-backed implant.

Stryker X3 polyethylene implant cemented on left cadaveric patellae					
Trial	AP depth before resurface	AP depth after resurface	AP depth after button placement	SI length (max)	ML width (max)
Cemented 1	26.42	16.33	22.82	54.54	49.90
Cemented 2	19.20	9.37	18.53	38.58	36.41
Cemented 3	28.20	16.73	24.01	46.49	51.59
Cemented 4	20.64	12.26	18.46	46.19	36.98
Cemented 5	27.47	18.26	24.39	48.61	48.12
Stryker Tritanium metal-backed implant press-fitted on right cadaveric patellae					
Trial	AP depth before resurface	AP depth after resurface	AP depth after button placement	SI length (max)	ML width (max)
Press-fit 1	26.39	16.28	24.46	55.46	49.59
Press-fit 2	19.22	9.48	19.72	41.67	37.66
Press-fit 3	27.84	16.32	24.14	49.17	54.46
Press-fit 4	20.36	11.43	19.37	45.40	37.87
Press-fit 5	27.13	18.58	24.68	47.64	48.52

All measurements are in millimeters.

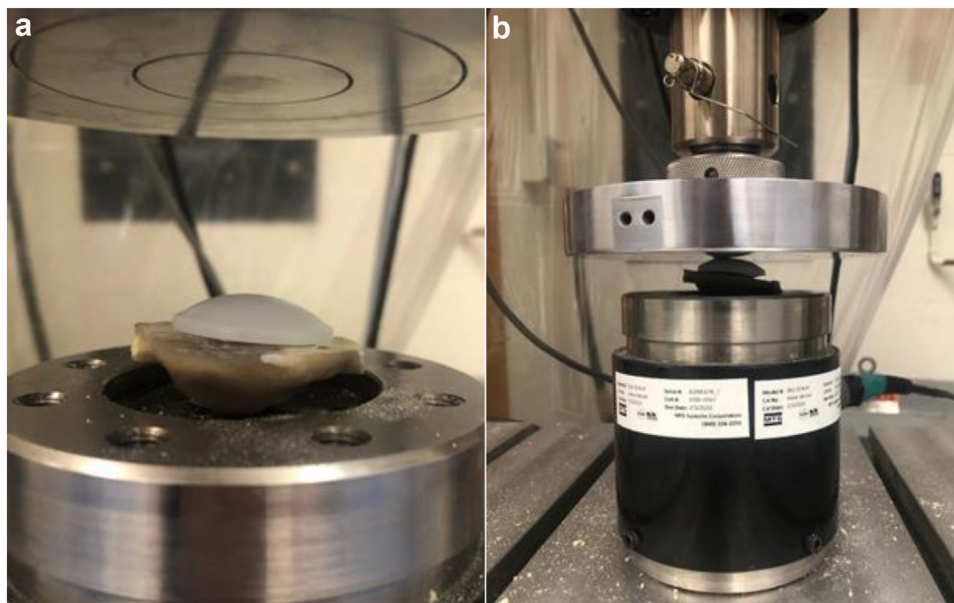


**Figure 2.** Prior to resurfacing, cadaveric patellae were harvested from matched pairs.

each construct was mounted onto the stationary load cell of the MTS Test System while the actuator was attached to a compression plate and used to load the button on the posterior side of the patella (Fig. 3). Initially, the construct was preloaded to 100N 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]. Then, the compression plate attached to the actuator descended at a rate of 5 mm/s in axial compression to apply a loading force perpendicular to the axis of the patella button until ultimate load to failure resulted in a patella fracture [29] (Fig. 4). The ultimate force and maximum displacement of the actuator at the time of fracture were recorded by the MTS Test System for each patella (Tables 3 and 4). To further adjust for the varying AP depths created during patellar resurfacing, the ultimate load to failure force per 1-mm AP depth of each fractured patella was calculated.

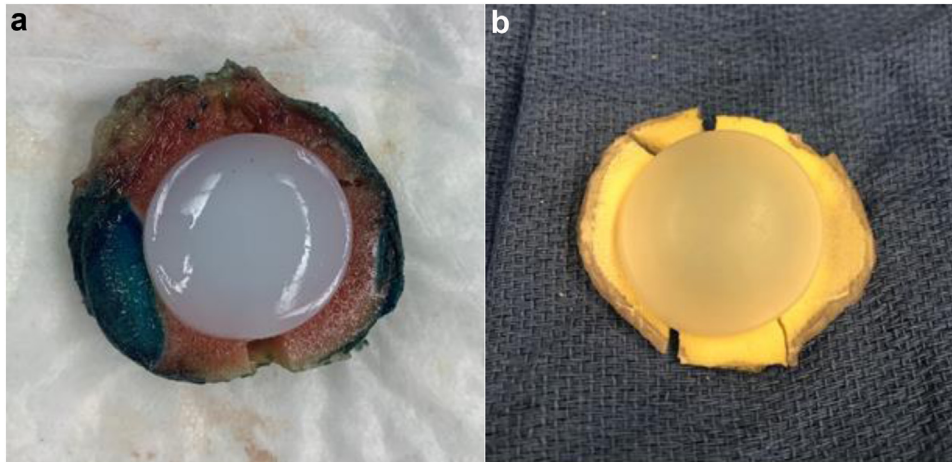
#### Statistical analysis

Statistical analysis was conducted in Microsoft Excel (Microsoft Corp., Redmond, WA) with the XLSTAT add-on (Addinsoft Inc., New York, NY). Mean values for ultimate load to failure, load to failure per 1-mm patellar thickness, maximum displacement at failure, and stiffness were compared for patellae fractured with the cemented polyethylene Stryker X3 implants vs the press-fit Stryker Tritanium metal-backed implants. In order to test the null hypothesis that biomechanical measurements were equivalent for the 2 implant types, a statistical analysis was performed with (1) a two-sided, paired Student's t-test for the cadaveric paired patellae and (2) a two-sided, independent samples Student's t-test for the composite patellae. A  $P < .05$  was considered statistically significant. All data are reported as mean  $\pm$  standard deviation.



**Figure 3.** Compression plate attached to the actuator of a biaxial servohydraulic testing machine (MTS Bionix 370; MTS Systems Corporation, Eden Prairie, MN) (a) before testing a resurfaced patella with implant and (b) after testing which resulted in a patella fracture from axial compression loading perpendicular to the axis of the patella button at a descending rate of 5 mm/s.





**Figure 4.** After recording the displacement and maximum load to failure force during MTS testing, a periprosthetic patellar fracture was observed in both (a) a cadaveric patella and (b) a composite patella.

## Results

### Composite bone model

For the composite patellae, the final average AP depth after button placement of both cemented polyethylene and press-fit metal-backed implants was  $22.75 \pm 1.23$  mm. The average maximum load to failure for the composite patellae with cemented implants was 4551.40 N compared with 6004.09 N for patellae with press-fit implants ( $P = .001$ ) (Table 5). There was no significant difference in the average maximum displacement required to cause a periprosthetic patellar fracture in the composite patellae with a cemented implant vs press-fit implant (4.02 vs 3.21 mm,  $P = .096$ ). After accounting for variations of AP depth between composite patellae, the mean maximum force per 1 mm of AP depth was significantly higher at 263.78 N for patellae with press-fit implants than the 200.37 N for patellae with cemented implants ( $P = .001$ ).

### Cadaveric specimen

For the cadaveric patellae, the final average AP depth after button placement of both cemented polyethylene and press-fit metal-backed implants was  $22.16 \pm 2.91$  mm. The average maximum load to failure for the cadaveric patellae with cemented implants was 5898.37 N compared with 4082.05 N for patellae with press-fit implants ( $P = .045$ ) (Table 6). There was no significant difference in the average maximum displacement required to cause a periprosthetic patellar fracture in the cadaveric specimens with a cemented implant compared with those with a press-fit implant (2.76 vs 2.46 mm,  $P = .338$ ). After accounting for variations of AP depth between cadaveric patellae, the mean maximum force per 1 mm of AP depth was higher at 274.61 N for patellae with cemented implants compared with 177.21 N for patellae with press-fit implants ( $P = .050$ ).

**Table 3**  
Biomechanical testing results of composite bone patellae with a cemented Stryker X3 polyethylene implant and with a press-fitted Stryker Tritanium metal-backed implant.

Stryker X3 polyethylene implant cemented on composite patellae			
Trial	Max compressive force (N)	Max displacement (mm)	Stiffness (N/mm)
Cemented 1	4979.82	4.13	1205.07
Cemented 2	4630.66	4.27	1083.32
Cemented 3	5355.99	5.13	1044.45
Cemented 4	3186.05	2.22	1435.87
Cemented 5	4890.27	2.60	1884.25
Cemented 6	4700.46	2.42	1943.22
Cemented 7	4492.76	2.96	1520.06
Cemented 8	5199.07	3.13	1660.85
Cemented 9	3227.36	2.55	1265.14
Cemented 10	4851.58	2.68	1807.00
Stryker Tritanium metal-backed implant press-fitted on composite patellae			
Trial	Max compressive force (N)	Max displacement (mm)	Stiffness (N/mm)
Press-fit 1	4572.09	1.78	2566.64
Press-fit 2	7865.24	3.80	2068.61
Press-fit 3	5507.65	4.95	1112.41
Press-fit 4	6597.22	3.58	1844.32
Press-fit 5	5551.05	5.34	1039.66
Press-fit 6	6869.97	5.34	1287.08
Press-fit 7	5442.30	4.10	1326.55
Press-fit 8	6617.54	3.12	2119.54
Press-fit 9	5834.92	4.44	1314.90
Press-fit 10	5182.96	3.73	1389.31

**Table 4**

Biomechanical testing results of matched cadaveric bone patellae with a cemented Stryker X3 polyethylene implant and with a press-fitted Stryker Tritanium metal-backed implant.

Stryker X3 polyethylene implant cemented on left cadaveric patellae			
Trial	Max compressive force (N)	Max displacement (mm)	Stiffness (N/mm)
Cemented 1	5753.73	1.92	3151.40
Cemented 2	3925.35	2.30	1619.40
Cemented 3	2403.08	3.19	698.75
Cemented 4	7227.00	3.02	1230.50
Cemented 5	10,182.69	3.39	3249.40
Stryker Tritanium metal-backed implant press-fitted on right cadaveric patellae			
Trial	Max compressive force (N)	Max displacement (mm)	Stiffness (N/mm)
Press-fit 1	5219.73	1.89	2619.40
Press-fit 2	1676.35	1.77	869.34
Press-fit 3	2047.35	3.84	528.86
Press-fit 4	3440.56	2.33	1426.70
Press-fit 5	8026.28	2.45	3474.90

## Discussion

The decision to resurface the patella during TKA has been controversial over the past few decades. In a study of 100 prospectively randomized patients, Mayman et al. reported 2 patients in the nonresurfaced group and one in the resurfaced group went on to require additional procedures secondary to patellar complications, but there was no difference between the 2 groups at 8–10 years of follow-up based on Knee Society and Clinical Ratings scores [30]. Additionally, a prospective randomized study of patellar resurfacing conducted by Barrack et al. yielded similar clinical results with no difference between TKA patients with and those without patellar resurfacing [31]. The study further demonstrated anterior knee pain improvement in the nonresurfaced group over time, whereas the resurfaced group had a higher rate of late-onset anterior knee pain [31]. In a subsequent study, Barrack et al. concluded the vast majority of patients, for whom patellar resurfacing is not done, do not report anterior knee pain at long-term follow up and, therefore, may avoid the complications associated with resurfacing of the patella [32]. Due to comparable long-term results with and without patellar resurfacing during TKA in the literature, a selective approach by identifying appropriate patients for resurfacing is used by some surgeons rather than routine resurfacing [33].

When indicated, patellar resurfacing has been documented to be cost-effective with a 4.6% reduction in the absolute risk of reoperation and a 13.85% reduction in the absolute risk of post-operative anterior knee pain in comparison to nonresurfacing [34–37]. Despite these benefits, patellar resurfacing has also been associated with complications including maltracking, implant

loosening, dislocation, osteonecrosis, extensor mechanism injury, and fracture [38,39]. As a source of failure following TKA with patellar resurfacing, patella fractures can result in severe pain and disability [40]. In a clinical trial, Leopold et al. determined regardless of concurrent lateral reticular release, revision of the isolated patellar component after TKA was associated with a high reoperation rate and a low rate of success [41]. Despite patella fractures being rare and accounting for 1% of all skeletal injuries, the incidence of periprosthetic patella fracture secondary to resurfacing following TKA has been documented to vary between 0.2% and 21% [42–46]. Additionally, a systematic review of 582 cases by Chalidis et al. reported 12% of post-TKA patellar fractures in resurfaced patients were due to a traumatic event and attributed these fractures to the implant design or surgical technique of arthroplasty [47]. While press-fit implants have historically been associated with increased failure rates, contemporary implant designs have decreased complication rates [39]. When compared with cemented buttons, the present study demonstrated press-fit metal-backed implants had a 36.4% lower ultimate load to failure than cemented polyethylene implants in cadaveric specimens; however, this finding was reversed in the composite models.

Based on the mechanism of injury, considerable variations exist in the morphology of patella fractures. These fractures can be described using the Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification system or according to the geometric configuration of fracture lines, which includes osteochondral, marginal, stellate, and linear patterns [48]. While pole avulsion injuries and transversely linear fractures are often due to rapid eccentric loading of the extensor mechanism, direct impact injuries more frequently result in comminuted or stellate-type fractures with 65% of these injuries being nondisplaced [49,50]. Accounting for 25% of all patella fractures, an epidemiological study by Larsen et al. reported AO fracture type 34-C3 to be the most common pattern, followed by AO fracture type 34-C1 representing 23% [51]. The present study is consistent with the previous literature as all trials in both cadaveric specimen and composite models resulted in stellate fracture patterns indicative of AO fracture type 34-C3. It is important to note fracture patterns may differ from our simulation, which tested the direct impact of a load on resurfaced patellae immediately after implantation.

Polymethyl methacrylate (PMMA) is an acrylic polymer created from the exothermic polymerization process after mixing a liquid MMA monomer with a powder MMA-styrene copolymer [52]. During implant placement, PMMA acts as a space-filler by reducing the space between the implant and bone [53]. With a lack of adhesive properties, PMMA relies on a mechanical interlock created between the irregular bone surface and the prosthesis [54]. Thus, PMMA interdigitates between the implant and bone. In the present study, the composite patellae models with press-fit metal-backed implants had a 27.52% higher ultimate load to failure than patellae with cemented polyethylene implants. This lower ultimate load to failure for the cemented implants in the composite patellae may reflect a lack of interdigitation in the polyethylene implant with the

**Table 5**

Average maximum force, average maximum displacement, average stiffness, and maximum force per 1-mm AP depth for composite patellae with a cemented Stryker X3 polyethylene implant and with a press-fitted Stryker Tritanium metal-backed implant.

Statistical analysis of cemented vs press-fit button implants in composite patellae			
Measurements	Cemented	Press-fit	P value
Average max compressive force (N) ± SD	4551.40 ± 753.11	6004.09 ± 969.68	.00149
Average max displacement (mm) ± SD	3.21 ± 0.97	4.02 ± 1.09	.09601
Average stiffness (N/mm) ± SD	1484.92 ± 331.62	1606.90 ± 509.16	.53354
Max force per 1 mm AP depth ± SD	200.37 ± 33.72	263.80 ± 39.54	.00115

Corresponding P values denote significance.

**Table 6**  
Average maximum force, average maximum displacement, average stiffness, and maximum force per 1-mm AP depth for matched cadaveric patellae with a cemented Stryker X3 polyethylene implant and with a press-fitted Stryker Tritanium metal-backed implant.

Statistical analysis of cemented vs press-fit button implants in cadaveric patellae			
Measurements	Cemented	Press-fit	P value
Average max compressive force (N) ± SD	5898.37 ± 3010.46	4082.05 ± 2607.21	.04507
Average max displacement (mm) ± SD	2.76 ± 0.63	2.46 ± 0.83	.33830
Average stiffness (N/mm) ± SD	1989.89 ± 1152.87	1783.84 ± 1234.57	.34772
Maximum force per 1-mm AP depth ± SD	274.61 ± 131.32	177.21 ± 100.31	.05007

Corresponding *P* values denote significance.

composite models, which differed in material properties. The hypothesis that interdigitation was less in composite models due to less cement penetration has not been validated by a direct measurement, but rather was an observation from the surgeon implanting the patellae. Conversely, the initial stability of the patella when representing a ground-level fall may have been improved with PMMA penetration into the cancellous bone of the cadaveric specimen. While it is unclear if PMMA alters the properties of composite patellae for biomechanical testing, this could certainly be an area of further investigation. Following biomechanical testing, no deformation was observed in the pegs of the metal-backed implants or in the pegs of the polyethylene implants. Differences in the modulus of elasticity of the metal-backed implants while interacting with the surrounding bone compared with that of the polyethylene implants while interacting with cement and the surrounding bone could have contributed to minor differences in the strain observed.

This study has several limitations. The composite substrate and cadaveric specimens utilized in this study were unable to completely mimic the biological properties of bone. Living bone has an intricate system of vasculature that provides blood to the surrounding tissue to promote healing and bony ingrowth of implants. Due to differing biology and bone quality contributing to variability of cadaveric samples, different ultimate loads to failure may be achieved in other specimens. As this study examined the immediate strength of the resurfaced patellae in the early postoperative period following TKA, bony ingrowth was not expected. Therefore, the studied patellae are representative of early in vivo patellar fractures at time zero and may not be indicative of ultimate load to failure or patterns of later fractures encountered in clinical practice in which ingrowth has occurred. With variations in the size and shape of cadaveric patellae, any type of pressure point could have skewed the results. However, this effect was minimized by pre-loading and ensuring uniform contact prior to loading to failure. Despite being designed to represent the native human patellae, the composite bone patellae differed in material composition and density. To mitigate this difference, acquired cadaveric specimen were tested with both implants by one adult reconstruction fellowship-trained orthopedic surgeon who performed all resurfacing and implant placement. Due to the absence of a standardized technique being used to resurface a patella and create a standard AP depth prior to button placement [55], the resurfaced patellae could have varied in AP depth, which may have affected the force required to cause a fracture. However, each matched cadaveric pair was resurfaced to have similar AP depths before implant testing to reduce these differences. Also, additional statistical analyses were performed to account for variability of patellae thickness after resurfacing by assessing the maximum force per 1 mm of depth of each patella. These adjustments assume that bone removal in 1-mm increments is linear, which is unlikely but would produce a more accurate result than not accommodating for this variable. Moreover, with all patellae being resurfaced and implanted using a single manufacturer system with one particular type of viscous

cement to further reduce variability, different results may be obtained when using materials from other manufacturers, TKA systems, implant designs, cement mixtures, and cement curation times. Lastly, although a significant difference in the maximum force per 1-mm thickness was detected for the composite models, a larger sample size may be needed to detect significant differences in cadaveric specimen.

## Conclusion

Although cadaveric patellae with cemented polyethylene button implants conferred additional strength in terms of a higher ultimate load to failure than patellae with press-fit metal-backed button implants, this finding was reversed in composite models. Differences in material properties and interdigitation of bone cement with cadaveric bone may account for these findings. Exploration of biological and composite model properties could provide further insight into patella button implant selection during TKA.

## Conflicts of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: F. L. Sanchez receives royalties from Medacta and Signature Orthopedics; is a paid consultant for Medacta, Biocomposites, and Link Orthopedics; receives research support as a principal investigator from Medacta; and is in the AAOS Knee Content Committee. All other authors declare no potential conflict of interest.

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