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Metal or Modularity: Why Do Metal-Backed Tibias Have Inferior Outcomes to All-Polyethylene Tibial Components in Patients With Osteoarthritis

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ABSTRACT

Background: Biomechanical studies have suggested improved stress distribution in metal-backed (MB) compared to all-polyethylene (AP) tibias, but such potential benefits have not been realized clinically. The purpose of this investigation was to analyze the outcomes of AP components in patients with primary osteoarthritis and compare the results to those obtained with MB tibial components in total knee arthroplasty (TKA).

Methods: We reviewed 11,653 patients undergoing primary TKA for osteoarthritis. There were 9999 (86%) MB (8470 modular and 1529 monoblock) and 1654 (14%) AP tibial components. All patients had at least 2 years of clinical follow-up with mean follow-up of 8 years (range, 2-30 years).

Results: Mean survivorship for all primary TKAs at the 5-year, 10-year, 15-year, and 20-year time points was 97%, 92%, 86%, and 78%. AP tibial components were found to have improved survivorship when compared to modular and monoblock MB counterparts ($P < .0001$). Likewise, AP tibial components were found to have lower rates of tibial component loosening ($P < .0001$), tibial osteolysis, and component fracture. Furthermore, the AP group had improved survival rates in most age-groups except <55 years where there was no difference. AP tibial components demonstrated improved survival for all body mass index (BMI) groups except in patients with a BMI ≤ 25 kg/m^2 where there was no difference.

Conclusion: AP tibial components had significantly improved implant survival across all age-groups and most BMI categories in patients who underwent TKA for osteoarthritis. Given these outcomes, AP tibias are a reasonable option, regardless of patient age and BMI.

Total knee arthroplasty (TKA) has become the standard of care for the treatment of advanced osteoarthritis of the knee joint, with an associated cost of several billion dollars every year [1-4]. All-polyethylene (AP) and monoblock metal-backed (MMB) tibial components represent some of the original condylar tibial component designs, with long-term survivorship over 90% [5-9]. Despite excellent results with these constructs, biomechanical studies in the 1980s and presumed “technical advantages” of modularity have led to widespread adoption of cemented metal-backed modular (MBM) tibial components in the United States [10-17].

While MBM components have become the most widely used tibial implant for TKA, multiple series have shown equivalent or improved long-term survivorship of AP tibial components when compared to either of their MB counterparts [4,8,9,15-22]. A noted limitation is that many of these cohorts report outcomes in patients with multiple underlying diagnoses, such as rheumatoid arthritis, post-traumatic arthritis, or osteoarthritis. The purpose of this study was to compare tibial component designs in patients with noninflammatory, atraumatic osteoarthritis. Specific attention was given to the following: (1) rates of revision, reoperation, and postoperative infection, (2) component failure subgrouped by body

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Table 1
Tibial Components Used in Patients With Primary Osteoarthritis.

All Knees	N = 11,653	% of Patients
Sigma	3688	31.6%
PFC	2714	23.2%
Genesis	1192	10.2%
Triathlon	1136	9.7%
Nexgen Legacy	862	7.4%
Kinematic Condylar II	664	5.7%
PCA	509	4.4%
Kinematic Condylar	357	3.1%
Total Condylar	158	1.4%
Omnifit	90	0.8%
Miller-Galant	74	0.7%
Attune	74	0.7%
Cruciate Condylar	72	0.6%
Genesis II	65	0.5%
Monoblock metal-backed	N = 1529	
Kinematic Condylar II	664	43.4%
Kinematic Condylar	357	23.3%
Total Condylar	158	10.4%
PCA	143	9.4%
Nexgen Legacy	135	8.8%
Cruciate Condylar	72	4.7%
All-polyethylene	N = 1654	
Sigma	1174	70.9%
Nexgen Legacy	239	14.5%
Genesis	135	8.2%
PFC	106	6.4%
Metal-backed modular	N = 8470	
PFC	2608	30.8%
Sigma	2514	29.7%
Triathlon	1136	13.4%
Genesis	1057	12.5%
Nexgen Legacy	488	5.6%
PCA	366	4.3%
Omnifit	90	1.1%
Miller-Galant	74	0.9%
Attune	74	0.9%
Genesis II	65	0.8%

PCA, porous-coated anatomic; PFC, press fit condylar.

mass index (BMI) and age-groups, and (3) rates of commonly described postoperative complications.

Materials and Methods

After obtaining approval from our institutional review board, we performed a review of all patients undergoing primary TKA using our institution's total joint database from 1982 to 2013. Before 1982, MBM knees were not commonly used at our institution. This registry prospectively follows patients at 2 and 5 years, and then every 5 years thereafter. Patients fill out a standardized data collection form which assesses pain and function [23].

Exclusion criteria included the following: procedures before 1982, unicompartmental procedures, revisions of a prior arthroplasty, prior surgical procedures on the knee, TKA with a cementless tibial component, implant designs that were used in less than 50 procedures, any diagnosis other than primary noninflammatory osteoarthritis, or follow-up less than 2 years. With these exclusions, 11,653 TKAs were included in our analysis, including 1529 MMB, 8470 MBM and 1654 AP tibial components (Table 1). There were 6794 women (58%) and 4859 men (42%), with a mean age of 71 years (range, 32-101 years), BMI of 31.8 kg/m^2 (range, 15.8-59.5 kg/m^2), and follow-up of 8 years (range, 2-30 years) (Table 2). Differences were detected between the 3 groups with respect to age, BMI, and sex (Table 2). The differences in age, BMI, and sex were primarily a product of the large sample size with differences between all 3 groups likely clinically insignificant (Table 2). Cruciate-retaining (CR) implants were present in 91% (n = 1384) of the MMB group, 45% (n = 3810) of the MBM group, and 23% (n = 383) of the AP group ($P < .0001$).

Primary outcome measures included revision surgery (removal of any component) and postoperative complications. A reoperation was defined as a procedure where the patient where anesthesia was induced, and the affected knee underwent a procedure. Besides revision procedures, indications for reoperation included wound revision, manipulation under anesthesia, open reduction internal fixation of a periprosthetic fracture, hematoma evacuation, extensor mechanism repair, painful hardware removal, bursal/neuroma excision, and debridement of patellar clunk. In an attempt to match the patient cohorts for the overall survival analysis, they were subgrouped based on BMI and age at the time of surgery. Captured complications from the clinical registry record included infection (deep and superficial), periprosthetic fracture, flexion contracture, tibial and femoral component loosening, and osteolysis. The diagnosis of a deep postoperative infection was based on the criteria set by the Musculoskeletal Infection Society [24].

Statistical Analysis

Kaplan-Meier survival methodology was used to make survivorship estimates, with comparisons between the MB and AP components performed using the log-rank test. Proportional hazard regression analysis was completed to assess the association of clinically interesting covariates with the risk of implant failure, reoperation, and postoperative infection. Continuous variables were compared using unpaired Student *t*-tests or analysis of variance, while categorical variables were compared with the Fisher exact test or chi-square test as appropriate. A statistical significance was set at a P value <.05.

Results

Revision Surgery

Over the course of the study, 724 knees (6.2%) were revised for any reason at a mean of 7 years (range, 1 week-22 years) postoperatively. The overall revision-free survival for all primary TKAs at the 5-year, 10-year, 15-year, and 20-year time points was 97%, 92%, 86%, and 78%, respectively. Compared to AP tibial components, the use of MMB (hazard ratio [HR], 3.37; $P < .0001$) or MBM (HR, 3.96; $P < .0001$) tibial components was associated with increased risk of revision (Table 3). There was no difference in the risk of

Table 2
Comparison of Patient Demographics.

Patient Demographics	Metal-Backed Modular (N = 8470)	Monoblock Metal-Backed (N = 1529)	All-Polyethylene (N = 1654)	*P* Value
Mean age ± SD (y)	70.2 ± 8.2	71.9 ± 7.6	72.5 ± 8.6	**.0001**
Mean BMI ± SD (kg/m^2)	31.9 ± 6.3	31.4 ± 6.2	31.2 ± 5.9	**.0001**
Mean polyethylene thickness ± SD (mm)	10.9 ± 2.5	8.3 ± 2.8	10.1 ± 1.9	**.0001**
Males, n (%)	3605 (43)	622 (41)	632 (38)	**.003**
Cruciate-retaining tibia, n (%)	3810 (45)	1384 (91)	383 (23)	**.0001**

Bold indicates statistical significance.
SD, standard deviation; BMI, body mass index.

Table 3
Comparison of MBM, MMB, and AP Tibias.

Comparison Groups	Revision, HR (95% CI)	*P* Value	Reoperation, HR (95% CI)	*P* Value	Infection, HR (95% CI)	*P* Value
All knees						
MBM vs AP	**3.96 (2.49-6.80)**	**<.0001**	**1.42 (1.14-1.80)**	**.003**	1.28 (0.87-1.96)	.20
MMB vs AP	**3.37 (2.06-5.92)**	**<.0001**	1.20 (0.92-1.57)	.16	1.02 (0.61-1.72)	.91
MBM vs MMB	1.17 (0.96-1.43)	.10	**1.18 (1.00-1.40)**	**.03**	1.24 (0.87-1.83)	.22
PS vs CR	0.97 (0.83-1.13)	.77	**1.20 (1.06-1.37)**	**.003**	1.12 (0.87-1.44)	.35
Age <55 y						
MBM vs AP	—	—	1.47 (0.64-4.26)	.38	—	—
MMB vs AP	—	—	1.44 (0.37-5.94)	.58	—	—
MBM vs MMB	2.01 (0.71-8.41)	.20	2.13 (0.87-7.07)	.10	—	—
PS vs CR	1.19 (0.57-2.57)	.64	1.27 (0.71-2.39)	.42	0.61 (0.16-2.92)	.50
Age 55-64 y						
MBM vs AP	**9.59 (2.14-168.88)**	**.0005**	**2.19 (1.19-4.62)**	**.009**	2.40 (0.73-14.80)	.16
MMB vs AP	**8.51 (1.81-151.82)**	**.002**	1.84 (0.92-4.09)	.08	1.08 (0.17-8.30)	.92
MBM vs MMB	1.12 (0.78-1.67)	.53	1.18 (0.85-1.69)	.30	2.21 (0.80-9.14)	.13
PS vs CR	1.19 (0.87-1.61)	.26	**1.36 (1.06-1.76)**	**.01**	0.72 (0.39-1.30)	.28
Age 65-74 y						
MBM vs AP	**3.03 (1.60-6.70)**	**.0002**	1.04 (0.76-1.46)	.79	1.16 (0.64-2.30)	.63
MMB vs AP	**2.77 (1.40-6.30)**	**.002**	0.94 (0.64-1.38)	.75	0.97 (0.45-2.19)	.95
MBM vs MMB	1.09 (0.83-1.45)	.52	1.10 (0.88-1.41)	.38	1.18 (0.70-2.13)	.53
PS vs CR	1.01 (0.79-1.29)	.89	1.11 (0.92-1.34)	.23	1.34 (0.92-1.94)	.11
Age 75+ y						
MBM vs AP	**2.65 (1.31-6.35)**	**.004**	1.39 (0.93-2.14)	.10	1.18 (0.67-2.26)	.57
MMB vs AP	**3.21 (1.47-8.05)**	**.002**	1.54 (0.96-2.52)	.07	1.18 (0.55-2.52)	.66
MBM vs MMB	0.82 (0.53-1.30)	.40	0.90 (0.65-1.27)	.54	1.00 (0.58-1.84)	.98
PS vs CR	0.90 (0.60-1.34)	.63	0.90 (0.68-1.19)	.47	1.15 (0.75-1.77)	.50
BMI ≤25 kg/m2						
MBM vs AP	1.42 (0.56-4.80)	.48	1.21 (0.66-2.44)	.55	3.02 (0.59-55.00)	.21
MMB vs AP	2.13 (0.41-9.79)	.33	1.52 (0.42-4.47)	.48	—	—
MBM vs MMB	0.66 (0.24-2.76)	.52	0.79 (0.32-2.61)	.66	—	
PS vs CR	1.10 (0.54-2.14)	.77	1.14 (0.71-1.84)	.57	1.99 (0.67-6.64)	.21
BMI 25 to <30 kg/m2						
MBM vs AP	**3.82 (1.74-10.81)**	**.0002**	**1.70 (1.11-2.74)**	**.01**	0.81 (0.43-1.65)	.55
MMB vs AP	**5.10 (1.74-16.71)**	**.003**	**2.50 (1.24-4.91)**	**.01**	0.91 (0.28-5.59)	.90
MBM vs MMB	0.75 (0.40-1.58)	.42	0.67 (0.41-1.22)	.18	1.12 (0.29-7.26)	.88
PS vs CR	1.27 (0.91-1.75)	.14	**1.34 (1.04-1.73)**	**.01**	1.14 (0.68-1.91)	.60
BMI 30 to <35 kg/m2						
MBM vs AP	**3.24 (1.46-9.17)**	**.002**	1.15 (0.78-1.76)	.47	1.18 (0.61-2.57)	.62
MMB vs AP	1.19 (0.17-5.54)	.83	1.04 (0.47-2.61)	.91	0.55 (0.03-2.95)	.54
MBM vs MMB	2.72 (0.86-16.46)	.09	1.20 (0.61-2.83)	.61	2.14 (0.47-37.84)	.39
PS vs CR	**1.66 (1.16-2.37)**	**.005**	**1.45 (1.11-1.90)**	**.005**	1.60 (0.96-2.73)	.06
BMI 35 to <40 kg/m2						
MBM vs AP	**11.19 (2.48-197.57)**	**.0002**	1.60 (0.93-2.98)	.08	1.44 (0.56-4.86)	.47
MMB vs AP	**12.38 (1.58-250.40)**	**.01**	1.09 (0.25-3.39)	.89	—	—
MBM vs MMB	1.35 (0.42-8.22)	.65	0.91 (0.29-3.99)	.89	—	—
PS vs CR	0.80 (0.50-1.25)	.33	0.94 (0.66-1.33)	.73	0.85 (0.42-1.76)	.66
BMI ≥40 kg/m2						
MBM vs AP	**3.19 (1.00-19.49)**	**.04**	1.15 (0.62-2.36)	.66	2.19 (0.66-13.52)	.22
MMB vs AP	**7.15 (1.39-51.71)**	**.01**	1.90 (0.59-5.38)	.25	—	—
MBM vs MMB	0.44 (0.18-1.47)	.16	0.60 (0.27-1.71)	.30	—	—
PS vs CR	0.75 (0.44-1.33)	.32	0.70 (0.47-1.08)	.11	0.36 (0.18-0.75)	.006

Bold indicates statistical significance.
MBM, metal-backed modular; MMB, monoblock metal-backed; AP, all-polyethylene; PS, posterior sacrificing; CR, cruciate retaining; BMI, body mass index; HR, hazard ratio; CI, confidence interval.

revision between the MBM components and the MMB (HR, 1.17; $P =$ .10) components. AP tibial components had improved survivorship ($P <$ .0001) compared to MB components across all time points (Fig. 1). Analysis of risk factors for revision in all knees showed that men (HR, 1.42; $P <$ .0001), morbidly obese patients (BMI >40 kg/m^2; HR, 1.75; $P <$ .0001), and those with a polyethylene thickness <8 mm (HR, 1.40; $P =$ .01) were at increased risk of revision. Obesity (BMI >30 kg/m^2; HR, 1.15; $P =$ .09) and use of a posterior-sacrificing (PS) compared to CR knee (HR, 1.12; $P =$ .15) were not associated with revision. In multivariate analysis, the use of MB components compared to an AP tibia was the strongest predictor of revision TKA (Table 4).

Based on age (Table 3), it was found that AP tibial components had improved revision-free survival compared to MBM and MMB components within the age-groups: 55-64 years (HR 9.59, $P =$ .0005 and HR 8.51, $P =$ .002), 65-74 years (HR 3.03, $P =$ .0002 and HR 2.77, $P =$ 2.77), and 75+ years (HR 2.65, $P =$ .004 and HR 3.21, $P =$ .002). Due to the limited number of events, HR could not be calculated for patients <55 years of age. When comparing the Kaplan-Meir survival curves for this age-group, there was no difference in the implant survival ($P =$ .09) between the AP and the MBM at the 5-year and 10-year (100% vs 93% and 100% vs 85%) time points and the AP and MMB (100% vs 93% and 100% vs 93%). When comparing the 2 MB components, there was no difference in the risk of revision surgery between MBM and MMB. There was no difference in revision-free survival based on cruciate-sacrificing or cruciate-sparing knee designs across all age-groups.

Patients with an MBM component were at significantly increased risk of revision compared to patients with an AP design for the BMI ranges of 25-30 kg/m^2 (HR, 3.82; $P =$ .0002), 30-35 kg/m^2 (HR, 3.24; $P =$ .002), 35-40 kg/m^2 (HR, 11.19; $P =$ .0002), and ≥40 kg/m^2 (HR, 3.19; $P =$ .04; Table 3). There was no difference in

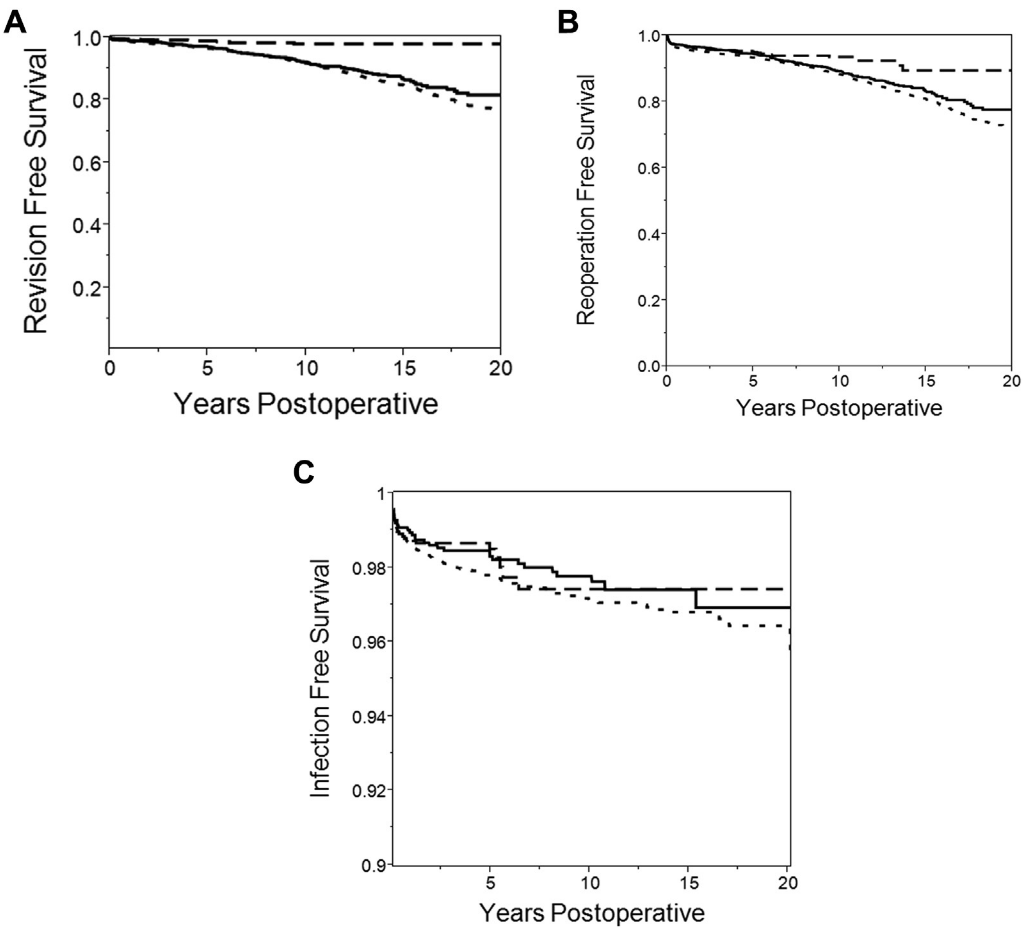

Fig. 1. Overall 25-year revision-free (A), reoperation-free (B), and infection-free (C) all-polyethylene tibial components (dashed), monoblock metal-backed (solid), and metal-backed modular (dot) tibial components. All-polyethylene components outperformed metal-backed components in terms of revision-free and reoperation-free survival. There was no difference in infection-free survival between the different tibial components.

revision-free survival between MBM and AP designs for patients with a BMI <25 kg/m^2 (HR, 1.42; $P = .48$). Likewise, patients with an MMB component were at increased risk of revision compared to patients with an AP design for the BMI ranges 25-30 kg/m^2 (HR, 5.10; $P = .003$), 30-35 kg/m^2 (HR, 12.38; $P = .01$), and ≥40 kg/m^2 (HR, 7.15; $P = .01$). There was no difference in revision-free survival at BMI <25 kg/m^2 (HR, 2.13; $P = .33$). There was no difference in revision-free survival between the MBM and MMB components over all BMI subgroups tested (Table 3). Patients with a PS tibial component were more likely to undergo revision surgery compared to those with a CR design at a BMI range of 30-35 kg/m^2 (HR, 1.66; $P = .005$); however, there was no difference at other subgroups.

Table 4
Multivariant Analysis of Risk Factors for Revision Total Knee.

All Knees	Revision	*P* Value
Males	**1.42 (1.19-1.69)**	**<.0001**
Obesity (BMI ≥30 kg/m^2)	1.04 (0.87-1.26)	.61
Morbid obesity (BMI ≥40 kg/m^2)	**1.72 (1.30-2.24)**	**.0002**
Posterior-sacrificing knee	**1.30 (1.07-1.57)**	**.006**
MBM vs AP	**3.77 (2.36-6.50)**	**<.0001**
MMB vs AP	**3.99 (2.06-7.87)**	**<.0001**
MBM vs MMB	0.94 (0.61-1.53)	.80

Bold indicates statistical significance.
MBM, metal-backed modular; MMB, monoblock metal-backed; AP, all-polyethylene; BMI, body mass index.

For the individual tibial component designs (Table 5), risk factors for revision surgery included male gender (HR, 1.34; $P = .0004$), morbid obesity (HR, 1.66; $P = .0003$), polyethylene thickness <8 mm (HR, 2.58; $P < .0001$), and a PS knee design (HR, 1.20; $P = .04$) in the MBM group. Likewise, male gender (HR, 1.68; $P = 0.004$) increased the risk of revision in the MMB group. No analyzed factor increased the risk of revision in the AP group.

Reoperation

Over the course of the study, 1132 patients (9.7%) experienced a reoperation for any reason at mean 5 years postoperative (range, 1 day-23 years). Overall reoperation-free survival for all primary TKAs at the 5-year, 10-year, 15-year, and 20-year time points was 94%, 88%, 81%, and 73%, respectively. AP tibial components had improved reoperation-free survivorship ($P = .002$) compared to MB components across all time points (Fig. 1). Compared to AP tibial components, the use of MBM (HR, 1.42; $P = .003$) tibial components was associated with an increased risk of reoperation; however, the use of an MMB (HR, 1.20; $P = .16$) was not (Table 3). When comparing the MB components, there was an increased risk of reoperation between MBM and MMB (HR, 1.18; $P = .03$) components. Males (HR, 1.13; $P = .03$), obese patients (HR, 1.16; $P = .03$), morbidly obese patients (HR, 1.62; $P < .0001$), and use of a PS compared to CR knee (HR, 1.20; $P = .003$) increased the risk of reoperation (Table 5).

Based on age (Table 3), it was found that MBM tibial components were at increased risk of reoperation compared to AP

Table 5
Risk Factors for Revision, Reoperation, and Infection in Total Knee Arthroplasty for Osteoarthritis.

Patient Demographics	Revision	P Value	Reoperation	P Value	Infection	P Value
All knees						
Males	**1.42 (1.23-1.64)**	**<.0001**	**1.13 (1.00-1.27)**	**.03**	1.22 (0.96-1.56)	.09
Obesity (BMI ≥30 kg/m^2)	1.15 (0.97-1.38)	.09	**1.16 (1.01-1.33)**	**.03**	**1.41 (1.07-1.89)**	**.01**
Morbid obesity (BMI ≥40 kg/m^2)	**1.75 (1.35-2.23)**	**<.0001**	**1.62 (1.33-1.95)**	**<.0001**	**1.70 (1.16-2.41)**	**.006**
Posterior-sacrificing knee	1.12 (0.95-1.32)	.15	**1.20 (1.06-1.37)**	**.003**	1.12 (0.87-1.44)	.35
Polyethylene thickness <8mm	**1.40 (1.07-1.80)**	**.01**	1.20 (0.95-1.50)	.10	1.00 (0.61-1.78)	.97
Metal-backed modular						
Males	**1.34 (1.13-1.57)**	**.0004**	1.08 (0.95-1.24)	.20	1.21 (0.92-1.60)	.16
Obesity (BMI ≥30 kg/m^2)	1.17 (0.97-1.40)	.08	1.14 (0.98-1.32)	.07	**1.47 (1.07-2.00)**	**.01**
Morbid obesity (BMI ≥40 kg/m^2)	**1.66 (1.26-2.13)**	**.0003**	**1.57 (1.27-1.92)**	**<.0001**	**1.81 (1.22-2.60)**	**.003**
Posterior-sacrificing knee	**1.20 (1.00-1.43)**	**.04**	**1.27 (1.10-1.47)**	**.0008**	1.20 (0.90-1.59)	.20
Polyethylene thickness <8mm	**2.58 (1.65-3.84)**	**<.0001**	**2.10 (1.43-2.97)**	**.0003**	1.36 (0.48-2.98)	.51
All-polyethylene						
Males	1.33 (0.47-3.57)	.57	1.34 (0.86-2.08)	.18	1.33 (0.61-2.84)	.46
Obesity (BMI ≥30 kg/m^2)	0.79 (0.29-2.16)	.65	1.38 (0.89-2.19)	.14	1.14 (0.53-2.54)	.72
Morbid obesity (BMI ≥40 kg/m^2)	1.80 (0.28-6.51)	.46	1.66 (0.80-3.08)	.15	0.94 (0.15-3.18)	.94
Posterior-sacrificing knee	0.81 (0.29-2.59)	.70	0.64 (0.40-1.03)	.07	0.81 (0.36-1.97)	.62
Polyethylene thickness <8mm	—	—	—	—	—	—
Monoblock metal-backed						
Males	**1.68 (1.18-2.40)**	**.004**	1.17 (0.86-1.59)	.30	1.16 (0.57-2.30)	.67
Obesity (BMI ≥30 kg/m^2)	0.84 (0.34-2.06)	.71	0.98 (0.49-1.98)	.96	1.45 (0.13-31.23)	.75
Morbid obesity (BMI ≥40 kg/m^2)	3.27 (0.93-9.03)	.06	**2.87 (1.06-6.56)**	**.03**	—	—
Posterior-sacrificing knee	1.91 (0.88-3.62)	.09	**2.13 (1.23-3.46)**	**.008**	0.39 (0.02-1.84)	.28
Polyethylene thickness <8mm	1.34 (0.83-2.17)	.22	1.07 (0.72-1.58)	.71	1.11 (0.45-2.70)	81

Bold indicates statistical significance.
BMI, body mass index.

components for ages 55-64 years (HR, 2.19; P = .009); however, there was no difference in the other age-groups. There was no increased risk of reoperation comparing the MMB to the AP tibial components across all age subgroups. When comparing the 2 MB components, there was no difference in the risk of reoperation between MBM and MMB based on any age category. Regarding PS and CR designs, there was an increased risk of reoperation for patients with a PS design between the ages of 55 and 64 years (HR, 1.36; P = .01).

Patients with an MBM component were at significantly increased risk of reoperation compared to patients with an AP design for the BMI range 25-30 kg/m^2 (HR, 1.70; P = .01); otherwise, there was no difference in reoperation-free survival based on the other BMI ranges examined (Table 3). Likewise, there was an increased risk of reoperation for MMB components compared to AP for the BMI range 25-30 kg/m^2 (HR, 2.50; P = .01); otherwise, there was no difference in reoperation-free survival based on the other BMI ranges examined. Patients with a PS tibial component were more likely to undergo a reoperation compared to those with a CR design at a BMI range of 25-30 kg/m^2 (HR, 1.34; P = .01) and 30-35 kg/m^2 (HR, 1.45; P = .005); however, there was no difference among the remaining subgroups.

For the individual tibial component designs (Table 5), risk factors for reoperation included morbid obesity (HR, 1.57; P < .0001), PS knee designs (HR, 1.27; P = .0008), and a polyethylene thickness of <8 mm (HR, 2.10; P = .0003) in the MBM group. Likewise, morbid obesity (HR, 2.87; P = .03) and the use of a PS knee design (HR, 2.13; P = .008) increased the risk of reoperation in the MMB group. No analyzed factor increased the risk of reoperation in the AP group.

Infection

Two-hundred sixty-four (2.2%) patients were diagnosed with a postoperative infection (superficial or deep) at a mean 2 years (range, 3 days to 20 years) postoperative. Overall infection-free survival for all primary TKAs at the 5-year, 10-year, 15-year, and 20-year time points was 98%, 97%, 97%, and 96%, respectively. Compared to AP tibial components, there was no difference in the risk of postoperative infection for MBM (HR, 1.28; P = .20) or MMB (HR, 1.02; P = .91) groups (Table 3). Specifically for the MB components, there was no difference in the risk of infection in patients with an MBM (HR, 1.24; P = .22) compared to an MMB component. Risk factors for a postoperative infection included obesity (HR, 1.41; P = .01) and morbid obesity (HR, 1.70; P = .006).

Based on age (Table 3), there was no increased risk of infection comparing all 3 implant groups and if the implant was a PS or a CR design. Likewise, there was no difference in the risk of postoperative infection between all 3 implant groups based on BMI or whether a PS or CR design was used in these BMI subgroups.

For the individual tibial component designs (Table 5), risk factors for postoperative infection included obesity (HR, 1.47; P = .01) and morbid obesity (HR, 1.81; P = .003) in the MBM group. No analyzed factor increased the risk of postoperative infection in the MMB and the AP group.

Complications

Postoperative complications occurred in 2641 (22.6%) patients. Patients with AP tibial components were less likely to have isolated tibial component loosening (P = .008), isolated femoral component loosening (P = .04), tibial osteolysis (P < .0001), and tibial component fracture (P = .03) compared to MB components (Table 6). There was no difference in the rate of tibial periprosthetic fracture between groups (P = .83). A majority of the patients with tibial polyethylene wear and osteolysis in the MBM cohort had their surgeries performed in the 1980s and the early 1990s, and these failures are likely related to implant sterilization and packaging methods which are no longer used.

In the AP tibial component group, patients were more likely to have a postoperative flexion contracture (P < .0001) and limited knee motion (P < .0001) compared to patients with MB tibial components (Table 6). We are unable to specifically comment on whether these implants were deliberately overstuffed, likewise cases occurred throughout the study, showing these cases are not likely due to a “learning” curve of this technique.

Table 6
Comparison of Complications in Total Knee Arthroplasty in Patients With Osteoarthritis.

Complication	Metal-Backed Modular (N = 8470)	Monoblock Metal-Backed (N = 1529)	All-Polyethylene (N = 1654)	*P* Value
Any infection	204 (2.4%)	33 (2.1%)	27 (1.6%)	.14
Superficial	72 (0.85%)	11 (0.71%)	11 (0.66%)	.68
Deep	138 (1.6%)	24 (1.5%)	16 (0.96%)	.13
Tibial component loosening	**55 (0.64%)**	**12 (0.78%)**	**1 (0.06%)**	**.008**
Femoral component loosening	**42 (0.49%)**	**7 (0.45%)**	**1 (0.06%)**	**.04**
Tibial component wear	**207 (2.4%)**	**29 (1.8%)**	**1 (0.06%)**	**<.0001**
Tibial osteolysis	**83 (0.97%)**	**7 (0.45%)**	**1 (0.06%)**	**<.0001**
Tibial periprosthetic fracture	24 (0.28%)	4 (0.26%)	6 (0.36%)	.83
Tibial component fracture	**25 (0.29%)**	**7 (0.45%)**	**0 (0.0%)**	**.03**
Limited motion	**216 (2.5%)**	**6 (0.39%)**	**40 (2.4%)**	**<.0001**
Flexion contracture	**225 (2.6%)**	**8 (0.52%)**	**59 (3.5%)**	**<.0001**

Bold indicates statistical significance.

Discussion

As multiple options exist for tibial components in TKA, the ideal implant should be both cost-conscious and provide reliable survivorship. With annual increases in the number of TKA being performed, debate remains regarding the optimal tibial component design. The results of this study show that in a large cohort of patients with a primary diagnosis of noninflammatory, atraumatic osteoarthritis, AP tibial components significantly outperform MBM as well as MMB components in terms of revision-free survival in univariant and multivariant analyses as well as across all age-groups and also a majority of BMIs.

Although one of the theoretical advantages of MBM components is the possibility of late liner exchange for wear, this historically accounts for less than 2% of revisions [25]. In contrast, modularity of the tibial component comes with a significant potential drawback, in terms of financial cost, creating another interface that may serve as a nidus for infection, as well as increased risk of backside wear and tibial osteolysis [26-30]. Results of this study support these findings. Monoblock (AP and MB) tibial components were found to have lower rates of tibial osteolysis, presumably due to less backside wear in these components. On the contrary, there was a higher rate of postoperative flexion contractures in patients with AP tibial components, but not with MMB components. This could be explained as an inherent disadvantage to the monoblock implant; however, we feel if this were the case, the risk of this complication would have been increased in both monoblock designs.

Infection is a primary cause of revision TKA in the United States [31]. Previous studies have shown an increased risk of infection in patients with an MB component compared to an AP tibial component [9]. Although we did not observe this same outcome comparing the individual MBM and MMB components compared to AP components, it has been theorized that the increased risk of infection in MBM components is due to polyethylene wear particles leading to an effusion, synovitis, and hyperemia, making the knee a “prosthesis at risk” for infection [32]. Given the substantial cost and resource utilization for treating prosthetic joint infections [33], the cost savings of an AP compared to a modular component are potentially amplified in the setting of a periprosthetic joint infection. It has been shown that cost of an AP tibial component would save the National Health Systems of England and Wales $39 million dollars if only half the TKAs performed each year were AP, not taking into account revision procedures [34]. Opponents of AP tibial components have claimed these implants create a disadvantage in not being able to perform a polyethylene exchange during a washout procedure. However, we do not believe this practice is necessary in AP components in the first place, as the goal of a polyethylene exchange during a washout is to clean implant interfaces, which can harbor infection. AP tibial components do not have an interface that could provide a nidus for infection in this setting, as such not needing an exchange, further enhancing the cost savings.

Because biomechanical studies had shown superior force distribution and decreased contact stress in MB components compared to AP, the use of AP components has been traditionally reserved for older, thinner, low-demand patients or those with rheumatoid arthritis who would not stress the tibial cancellous bone [22,35-38]. Despite this dogma, Ranawat et al [39] previously showed that AP tibial components can be successfully used in patients younger than 60 years; however, this study did not have a comparison group. The results of this study show that AP tibial components have similar outcome in terms of revision-free survival across all age-groups, and specifically no difference in survival in younger patients.

With the obesity epidemic affecting over a third of people in the United States, and the fact that obesity increases the risk of osteoarthritis, there is an increased incidence of TKA in obese patients [40,41]. Based on the results of biomechanical studies, AP components should be used with caution in obese patients due to increased load across the knee, although this has not translated clinically. Studies by Toman et al and Dalury et al found no difference in survival of AP tibial components compared to MB components in obese patients [22,42]. The results of this study support these findings where the mean BMI was obese (31.8 kg/m^2), and in subgroup analysis with commonly used BMI cutoffs, there was improved survivorship of AP components compared to MB components. The only group where no difference was observed was in those with a BMI $\leq$25 kg/m^2, where the benefits of biomechanically superior design should not have the same magnitude of impact. Obesity and morbid obesity were not risk factors for revision in patients with AP tibial components; however, morbid obesity increased the risk of revision in patients with modular components.

Although the groups were similar, one significant difference in the groups was the percentage of male patients in the AP group. Previous studies have shown higher rates of revision TKA in male patients compared to females due to increased physical demand and biomechanical differences [43-46]. As such, we would have expected there to be a higher rate of revision in AP group; however, the exact opposite was observed.

Tibial polyethylene insert thickness has previously been shown to be a risk factor for failure [11,47-49]. In previous series, a minimal polyethylene thickness of 8 mm has been recommended and the results of this study support this finding. In this series, patients with a polyethylene component thickness <8 mm were at increased risk of revision, however only in the MBM group. It was surprising that although the MMB group had the thinnest polyethylene thickness, there was no increased risk of failure. This is likely due to the lack of potential backside wear in the MMB component compared to the MBM component. In line with other series, we recommend for the use of at least an 8-mm tibial component when an MBM tibia is used.

This study should be interpreted with certain limitations. The prospective nature of the registry data helps to reduce recall and selection bias, but the data were examined retrospectively and as such we were limited to the information contained in the registry. This study is also limited to the experience of a single institution with multiple surgeons performing the operation. As such, there is selection bias in the patient population and because this report is limited to a single institution the individual patient demands on the implants cannot be extracted to all patients. Currently, there is no standardized system of determining which patient undergoes an AP vs an MB tibial component design at our institution. All surgeons included in this study performed both MB and AP TKAs during the study period. Likewise, the sample does include implants that are no longer available for use in the United States.

Overall, the results of this study show AP tibial components were associated with a lower rate of revision in patients with osteoarthritis. The lower complication rates in conjunction with the historic lower cost give credence to their use, despite the fact that they currently constitute only a minority of cases performed in the United States each year. However, this report is not meant to endorse widespread use in all patients as it remains a more technically challenging operation in some patients. What seems most apparent from the present study is that contrary to historical reports, this large series demonstrates AP tibial components provide a durable, long-term option for primary TKA regardless of age and BMI.

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