All-polyethylene and Metal-backed Tibial Components Are Equivalent With BMI of Less Than 37.5

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Abstract

Background Modular, metal-backed tibial (MBT) components are associated with locking mechanism dysfunction, breakage, backside wear, and osteolysis, which compromise survivorship. All-polyethylene tibial (APT) components eliminate problems associated with MBTs, but, historically, APT utilization has generally been limited to older, less active patients. However, it is unclear whether APT utilization can be expanded to a nonselected patient population. **Questions/purposes** We therefore determined the survivorship of APT components compared with MBT components in a non-age- or activity-selected population who underwent TKA.

Methods Using a longitudinal database, we identified 775 patients with primary TKAs utilizing a single implant design between 1999 and 2007. Of these, 558 (72%) patients had APT components (APT2), while 217 (28%) patients with tibial bone loss or defects, contralateral MBT components, or a BMI of greater than 37.5 received MBT components. We determined the survivorship in the two

groups. The minimum followup was 2 years for both groups (mean $\pm$ SD: MBT, 80 ± 29 months; APT, 63 ± 27 months). The APT group was older (average age: APT2, 70 years; MBT, 64.7 years) and had a lower BMI than the MBT group (APT2, 30.8; MBT, 33.8).

Results Survivorship, as defined by revision for any reason, was 99% for the APT group and 97% for the MBT group. There were four (2%) tibial failures in the MBT group in patients with a BMI of greater than 40. There were no revisions for loosening or osteolysis in the APT group. **Conclusion** APT implants perform as well as MBT implants in a non-age- or activity-selected TKA population with a BMI of less than 37.5.

Level of Evidence Level III, therapeutic study. See Guidelines for Authors for a complete description of levels of evidence.

Introduction

Early TKA designs used cemented all-polyethylene tibial (APT) components [6, 7, 9, 12, 18, 21, 28, 33, 38, 39]. Both posterior-cruciate-preserving and posterior-cruciate-substituting designs utilizing polymethylmethacrylate bone cement for fixation showed greater than 90% survivorship at followup of 10 or more years [11, 31, 32, 36, 37]. APT utilization decreased markedly in the late 1980s and 1990s due to several concerning reports about APT components [6, 7, 9, 10, 12]. Metal-backed tibial (MBT) components with modularity were introduced to improve intraoperative flexibility [11, 21, 36], provide options for revision surgery, and improve the survivorship of the tibial implant [2, 37, 38] by improving load transfer to the tibial plateau and improving fixation [33, 38, 39].

One author (WLH) has a product development agreement with DePuy Orthopaedics Inc, a Johnson and Johnson company (Warsaw, IN, USA). No institutional support was received for this study. *Clinical Orthopaedics and Related Research* neither advocates nor endorses the use of any treatment, drug, or device. Readers are encouraged to always seek additional information, including FDA approval status, of any drug or device before clinical use. Each author certifies that his or her institution approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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However, in the late 1990s, the benefits of modular MBT components were questioned by reports of backside wear of the polyethylene modular insert, poorly functioning tibial base plate locking mechanisms, and osteolysis associated with these problems [4, 8, 24, 27]. Alternatives to MBT components were therefore developed. Mobile-bearing tibial components, nonmodular MBT components, and improved versions of MBT components with better locking mechanisms and improved polyethylene sterilization techniques became available. Modern MBT components continue to be the most commonly used tibial implant [11, 13, 17, 35].

Although some early cemented APT components provided survivorship ranging from 96% to 98%, with revision as an end point at 5 to 14 years of followup [18, 28], survivorship rates of 72% to 90% at 5 to 10 years' followup were reported in some TKA designs when indications were expanded to a higher-demand patient population [7, 10, 11, 31, 32, 37]. Consequently, APT components became less frequently utilized, most often being implanted in older or lower-demand patients [1, 22, 26]. In the late 1990s, the survivorship of APT components in low-demand patients was greater than 95% at 10 or more years of followup, and utilization in non-age- or activity-selected patients began [3, 5, 14, 25, 29, 32, 34]. Surgeons implanted APT components fabricated with polyethylene sterilized with gamma irradiation and sealed in a vacuum, designed with a stiff tibial keel, and manufactured in a variety of sizes to cover the proximal tibial cortical surface in patients throughout the demand spectrum. Previous studies have limited use of APT components in elderly or low-demand patients [1, 9, 22, 26, 28, 29]. In this study, we expanded the use of APT components to a non-age- or activity-selected population.

APT components are less expensive than other tibial implants, and the demand for TKA is projected to increase over the next 20 years [20]. In 2008, total joint arthroplasty accounted for the single largest outlay of Center for Medicare & Medicaid Services funds for a single-diagnosis-related group [16, 20, 23]. In the face of rising costs, declining revenues, and increasing demand, there was a renewed interest in assessing APT components in TKA [3, 13–16, 19, 25, 26]. While MBT components offered increased options in terms of stems and augments for complex primary or revision TKAs, the majority of patients undergoing TKA did not require this degree of intraoperative versatility [13, 14].

We therefore determined whether (1) a non-age- and activity-selected patient population would have equivalent survivorship and complication rates (reoperation, osteolysis, tibial implant loosening) using APT and MBT tibial implants, (2) a BMI of greater than 37.5 would affect survivorship in the MBT cohort, and (3) a historical control

population with APT components used in an elderly, low-demand population would maintain previously reported survivorship at long-term followup.

Patients and Materials

Using an institutional database, we identified 823 knees in 664 patients who underwent TKA by the operating surgeon (RI) between 1999 and 2007. From 1992 to 1998, the Lahey Clinic only utilized APT components (PFC®; DePuy Orthopaedics Inc, a Johnson and Johnson company, Warsaw, IN, USA) only in low-demand (Lahey Clinic Demand Category 4) [19] or elderly (older than 75 years) patients (APT1). The implant was a posterior-cruciate-substituting design, and the femoral component did not have lugs on the distal femur. All other patients had MBT components from the same manufacturer implanted. In late 1998, one surgeon (RI) elected to use APT components (PFC® Sigma®) for primary TKA in almost all patients, without regard for age or activity, due to concerns about the performance of MBT components. The femoral component had lugs in all cases after January 1, 1999. The APT component design did not change. After January 1, 1999, patients undergoing TKA received APT components if their BMI was less than 37.5, there were no proximal tibial bone defects, and they did not have a MBT component implanted on a contralateral knee before index surgery. Patients with a BMI of greater than 37.5, proximal tibial bone defects, and a preexisting MBT component on the contralateral side received a MBT component (MBT routine and high BMI/demand). Eighteen of the 823 patients (20 TKAs) did not have adequate 2-year clinical or radiographic followup for inclusion in this study. Twenty-six patients (28 TKA) died before the 2-year followup interval. This left 775 knees in 620 patients for study.

We included 76 APT components implanted in 59 patients from 1994 to 1999 (APT1) in this study for historical, longitudinal survivorship analysis. These patients were typically older and low-demand and were a small portion of the cohort of patients undergoing TKA before 1999 (Lahey Clinic Demand Category 3 or 4) [19]. For comparative purposes, we only included the APT2 (TKA after 1999) ($n = 558$) and MBT ($n = 217$) components implanted from 1999 to 2007 in the main analysis (Table 1). We subdivided the MBT group further into MBT routine BMI/demand (MBT-3B) and high BMI/demand (MBT-3A) groups to standardize comparison with the APT2 cohort. There were 62 patients in the MBT-3B group who had a MBT component on the contralateral side and 155 patients in the MBT-3A group who had a BMI of greater than 37.5 or proximal tibial bone defects (three of 155, 1.9%) (Table 2).

The average BMI values differed between the two groups: the APT2 group averaged 30.8 and the MBT group averaged 33.8 (95% CI, 1.96–4.08) (Table 1). Twenty-two of 217 TKAs (9.1%) were simultaneously bilateral in the MBT group and 40 of 558 (7.3%) in the APT2 group. The primary preoperative diagnosis for all groups was osteoarthritis. Average radiographic and clinical followup was

longer for the MBT group (Table 1). Comparison between the younger and heavier MBT-3A and MBT-3B groups demonstrated differences in terms of BMI (95% CI, 12.47–15.11) and age at time of surgery (95% CI, –9.44 to –4.67).

One surgeon (RI) performed all operations at one high-volume academic medical center utilizing a standardized clinical care pathway during the entire study period [15, 19]. All TKA operations were three-compartment resurfacing cemented arthroplasties in which the surgeon inserted a condylar prosthesis through a medial parapatellar arthrotomy. All implants for primary TKA were posterior-cruciate-substituting design, with either an APT or MBT tibial component. Preferred femoral alignment was 5° of valgus. Preferred tibial alignment was parallel to the ankle and/or perpendicular to the mechanical axis with 3° of posterior slope. The surgeon used Specialist One instruments (DePuy Orthopaedics Inc) as alignment and cutting guides. He placed tibial components in identical fashion: he pulse-lavaged the cut tibial surface, dried it, and manually impacted it with cement into the tibia. The surgeon also placed cement on the bone-facing surface of either component type before implantation and impaction. The details of the operative technique and postoperative management followed an identical protocol between the two groups [15, 19]. Patients met for radiographic followup at 6 weeks, 1 year, and biannually thereafter. If for any reason patients did not return for radiographic followup, we contacted them to return for radiographic followup and queried them about the TKA concerning reoperations. Sixty-one patients had confirmation of implant survival without radiographic evaluation of the knee implant within 2 years of closing this study.

One author (JT) reviewed all postoperative radiographs. Then, one of the senior authors (RI) also reviewed positive

Table 1. Patient characteristics for the APT2 and MBT groups

Characteristic	MBT (n = 217)	APT2 (n = 558)	p value or 95% CI between APT2 and MBT
Sex			p = 0.81
Male	84 (38.7%)	223 (40%)	
Female	133 (61.3%)	335 (60%)	
Mean age at time of surgery (years)	64.7	70.1	CI –6.83 to –4.00
Mean height (cm)	167.1	166	CI –0.87 to –2.97
Mean weight (kg)	95	84.9	CI 7.06 to 13.10
Mean BMI	33.8	30.8	CI 2.00 to 4.01
Mean clinical followup (months)	80 (SD, 28.5)	63 (SD, 27.4)	CI 12.82 to 21.52
Radiographic followup			
Mean (months)	51	34	CI 12.15 to 20.00
Range (months)	1–122	1–123	
Bilateral TKAs	22 (9.1%)	40 (7.3%)	p = 0.22
Preoperative diagnosis			
Osteoarthritis	96.0%	96.0%	
Osteonecrosis	NA	1.6%	
Rheumatoid	3.0%	1.6%	
Posttraumatic	1.0%	0/7%	

MBT = metal-backed tibia; APT2 = all-polyethylene tibia after 1999; NA = not applicable.

Table 2. Patient characteristics for the APT2 and MBT-3A and MBT-3B patients

Characteristic	MBT-3A (n = 155)	MBT-3B (n = 62)	APT2 (n = 558)	95% CI between APT2 and MBT-3B
Sex				
Male	60 (38%)	24 (39%)	223 (40%)	
Female	95 (62%)	38 (61%)	335 (60%)	
Age at time of surgery (years)	62.8	69.5	70.11	
Mean height (cm)	156.6	169.3	166	
Mean weight (kg)	104.5	96.26	84.9	CI –14.66 to –6.30
Mean BMI	40.4	33.49	30.8	CI –3.85 to –0.45
Radiographic followup				
Mean (months)	55	42	34	
Range (months)	1–122	1–109	1–123	

MBT-3A = metal-backed tibia, high BMI/demand (BMI > 37.5); MBT-3B = metal-backed tibia, routine BMI/demand (BMI < 37.5); APT2 = all-polyethylene tibia after 1999.

radiographic findings for confirmation. We defined osteolysis as an area of focal bone resorption identified by the absence of radiodense bony trabeculae and/or an area of reactive bone formation around a metaphyseal or epiphyseal osseous defect. We compared any such findings on followup films to the 6-week postoperative radiographs and, if the lucent area represented a change, recorded it as osteolysis, following it closely for the manifestation of symptoms or change in component position. We also evaluated radiolucencies at each followup interval and noted progressive radiolucencies of greater than 1 mm as evidence of possible loosening. We did not consider lucencies that were greater than 1 mm, but not progressive, as an indication of loosening [14, 24]. We recorded major complications, those occurrences that would impact survivorship or cause a reoperation, and reoperations for all patients. We considered instability, periprosthetic fracture, infection, loosening, synovitis, crepitus, and patella-femoral clunk as possible indications for reoperation and recorded them, as well as reoperations for instability, open reduction and internal fixation of a periprosthetic fracture, infection, loosening, synovitis, or patellar-femoral clunk.

The main outcomes we examined were failure of the tibial component and survivorship of the implant, defined by need for revision of the TKA for any reason. We recorded clinical and radiographic assessment for 217 MBT, 76 APT1, and 558 APT2 operations. We determined differences between revision, reoperation, and complication rates between the APT2 and MBT groups with a chi square analysis. We performed additional analysis between the APT2 and the MBT-3A and MBT-3B cohorts. We analyzed survivorship of the implant using Kaplan-Meier survival analysis with two end points: (1) revision of the TKA operation for any reason and (2) tibial revision; we

then determined differences in rates of survivorship between groups. We performed all statistical analysis using SPSS® software (v11.5; SPSS Inc, Chicago, IL, USA).

Results

Failure of the implant for any reason, such that revision operation was necessary, occurred in six (1.1%) APT2 knees and six (2.8%) MBT knees. Survivorship analysis that compared the APT2 and MBT groups using revision operation for any reason as an end point was similar at all followup intervals (Fig. 1). Survivorship analysis that compared the APT2 and MBT groups using tibial failure as an end point was similar at all followup intervals (Fig. 2). Failure of the tibial implant was observed in four (1.8%) of the MBT patients and none of the APT patients in either cohort.

The APT1 TKAs had no isolated tibial component failures and no revisions for loosening of any component.

Survivorship analysis revealed, for revision for any reason (Fig. 2) or tibial failure (Fig. 3) the MBT-3A cohort had decreased survivorship when compared to the APT2 group or the MBT-3B group. Both of the MBT groups were heavier than the APT2 group. The MBT-3A group was younger than the APT2 cohort (Table 2). Additionally, there were four knees in the MBT-3A group with aseptic tibial loosening for which we performed revision, but none in the MBT-3B group.

Complications requiring a return to the operating room included revisions for any reason (APT2: two for deep infections, two for instability, two for stiffness; MBT: two for deep infections, four for tibial failures [all in the MBT-3A]). Supracondylar fractures (MBT: one), extensor

Fig. 1 A graph shows survivorship of the entire implant for any reason for the MBT and APT2 groups. There were no aseptic tibial failures in the APT2 group.

Fig. 2 A graph shows survivorship of the tibial implant for the MBT and APT2 groups. There were no aseptic tibial failures in the APT2 group.

Fig. 3 A graph shows survivorship of the tibial implant for the MBT-3A, MBT-3B, and APT2 groups. The MBT-3B group includes four aseptic tibial failures in patients with a BMI of greater than 40.

mechanism interruptions (APT2: four; MBT: two), refractory knee stiffness for which we performed manipulation (APT2: one; MBT: one), and synovitis or clunk for which we performed arthroscopic débridement (APT2: 10; MBT: three) comprised the remainder of the complications requiring return to the operating room. These complications lead to reoperation in 21 (3.8%) patients in the APT2 group and 13 (6%) in the MBT group. There were no cases of osteolysis, progressive radiolucency, femoral or tibial implant loosening, or breakage in either APT cohort. Reoperation for tibial component failure ($p < 0.001$), occurring exclusively in the MBT-3A group (four of 135, 3%), was the only reoperation demonstrating a statistical difference in intervention rate between groups.

Discussion

The aging demographic of the US population, a decreasing age of intervention, and the success of TKA are expected to drive annual demand for TKA from the current level of approximately 600,000 to between 3 and 4 million procedures per year by 2030 [20]. MBT components are the most commonly used tibial implants [13, 14]. The largest expense for TKA is the cost of the implant [15, 23]. One method to reduce individual case expenditures for TKA is the use of APT components, which can provide savings of \$300 to \$750 per case when compared with MBT components [13–15, 23]. We therefore determined whether (1) a non-age- and activity-selected patient population had

equivalent survivorship and complication rates (reoperation, osteolysis, tibial implant loosening) using APT and MBT tibial implants, (2) BMI would have an effect on tibial implant survivorship, and (3) a historical control population with APT components used in an elderly, low-demand population would maintain previously reported survivorship at long-term followup.

There are several limitations in this study. First, the retrospective nature of the study reflects selection bias based on indications at the time of surgery. Therefore, the choice of tibial implant was not randomized between groups. We made no attempt to match patients in the APT and MBT groups in terms of demographics or demand profile, which may be a source of bias or confounding variables. The younger age, larger BMI, and longer followup for the MBT group may bias the survivorship statistics since the APT group is older, smaller, and followed for shorter intervals. However, we designed this longitudinal, observational study to capture a broad cross section of primary TKA patients without special implants or surgical techniques. Second, we only included patients available for 2-year followup. However, 90% of the knees had at least 2-year followup, so we do not believe this would jeopardize the conclusions. We evaluated patients without adequate radiographic followup via telephone and checked their medical records to confirm survivorship of the implant and any reoperations. Third, we used components from a single implant manufacturer, with a single implant geometry, and reported only the experience of a single surgeon, with a standardized perioperative protocol at a high-volume, academic, joint arthroplasty setting. While this reduced variability, it may also have made the conclusions less generalizable.

Several retrospective, nonrandomized, or matched-pair analyses reinforce the survivorship equivalence between APT and MBT components in cemented TKA (Table 3) [1, 3, 5, 11, 14, 18, 26–29, 32, 34]. More recently, there have been several double-blind, randomized, controlled trials comparing TKA with APT and MBT components. Gioe et al. [13] randomized 316 TKAs to APT or MBT tibial implants, following them for 8 to 12 years, and noted no differences at 10 years regarding subjective knee function, clinical examination, or radiographic findings. The 10-year survivorship of TKA with APT components was 91.6% versus 88.9% for TKA with MBT components. Although the overall rate of TKA revision for any reason was similar between the groups, three MBT components underwent revision for aseptic loosening of the tibial component, while no APT component had a revision. Muller et al. [25] reported equivalent negligible rates of tibial component migration (< 1 mm) between cemented APT and MBT components at 24 months.

The results of our series of 851 TKAs were consistent with recent literature confirming excellent survivorship of

APT implants in a broad cross section of TKA patients [1, 3, 5, 14, 18, 22, 25, 26, 29, 32, 34]. The operative surgeon had previous experience with APT components, illustrated by the clinical results of the APT1 group in this study and a previous study [26]. His experience eliminated any learning curve issues with wide spread use of APT components.

We implanted APT components in all patients except those with tibial bone defects, BMI of greater than 37.5, or a preexisting contralateral MBT component. When we stratified the MBT group according to BMI and demand profile, we observed a relatively similar rate of TKA revision for any reason (3.8% in MBT-3A and 3.2% in MBT-3B). The MBT-3A group exhibited a 2.6% (four of 155 TKAs) revision rate for aseptic loosening of the tibial implant, different when compared to the APT2 group, which had no tibial revisions for loosening. However, patients in the MBT-3A group were heavier (BMI range, 40.4–30.8) and younger (age range, 63–70 years) than the APT2 group. The MBT-3B group was slightly heavier (BMI range, 33.5–30.8) but similarly aged when compared with the APT2 group. In the MBT-3B, we noted no tibial failures secondary to loosening.

All aseptic tibial revisions in this study occurred in the largest patients (BMI > 40) with MBT components. The largest patients remain problematic for modern TKA. No patient with a BMI of greater than 37.5 received an APT component in this study. It remains to be seen whether APT components may be more enduring in the super obese than MBT components. Two studies from the same institution [31, 34] reported only one failure and good overall results after 2 to 11 years' followup of 242 APT components in younger, more active TKA patients. The results of this study include younger patients, and the 98.9% survivorship is similar to previous studies of APT components demonstrating survivorships of greater than 97% at more than 10 years of followup in older patients [3, 5, 14, 22, 25, 28, 29, 34]. The results of the APT1 group, with no revisions noted at an average 152 months of followup, validate the enduring performance of APT components in an age- and activity-selected patient population. It remains to be seen whether the APT2 group will match this performance in a population not selected by age or activity but limited to patients with a BMI of less than 37.5.

The cost savings of APT components (at least \$300 per case) was noted as early as 1991 [1]. Subsequently, Gioe et al. [13] found a savings of \$675 per case, and in a recent study, the same group [14] noted APT components averaged \$729 less than MBT components. However, the profit margin realized by hospitals for TKA continues to decline. In some hospitals, TKA is performed at a net loss [15, 16, 30, 35]. Since the early 1990s, diagnosis-related group payments for total joint arthroplasty have failed to keep pace with inflation, and the costs associated with TKA patient

Table 3. Literature results of APT components since 1990

Study	Year	Implant(s)	Age at operation (years)*	Average followup (years)	Number of MBTs	Number of APTs	Revisions/failures due to osteolysis, aseptic loosening	
							MBT	APT
Apel et al. [1]	1991	Total condylar	63 (32–85)	6	69	62	0 (0%)	0 (0%)
Rand [32]	1993	Cruciate-sparing total condylar	62 (26–83)	10	129	61	1 (0.8%)	1 (1.6%)
Font-Rodriguez et al. [11]	1997	Total condylar posterior-stabilized IB1, IB2	66.5 (17–87)	21	2036	480	8 (0.4%)	17 (3.5%)
Pagnano et al. [28]	1999	Cruciate condylar	79 (75–88)	10		81		0 (0%)
Pomeroy et al. [29]	2000	PFC	75 (61–99)	3		312		0 (0%)
Rodriguez et al. [34]	2001	PFC	70 (27–88)	5.5	113	130	5 (4.4%)	0 (0%)
O'Rourke et al. [27]	2002	Total condylar posterior-stabilized IB2	MBT 69 (49–84) APT 76 (69–85)	6.4	145	31	2 (1.4%)	0 (0%)
Najibi et al. [26]	2003	PFC®	78 (59–71)	6	49	49	0 (0%)	0 (0%)
Faris et al. [10]	2003	AGC®	70.3 (34–91)	10		536		58 (10.8%)
Gioe et al. [13]	2006	PFC®	69 (60–91)	9.6	70	97	3 (4.3%)	0 (0%)
Gioe et al. [14]	2007	DePuy, Wright, Osteonics	APT 77 (59–84) MBT 70 (58–99)	5	4977	443	48 (0.96%)	2 (0.45%)
Dalury et al. [5]	2009	PFC®	76.4 (62–93)	7+		88		0 (0%)
Bettinson et al. [3]	2009	Kinemax® Plus	69.3 (50–93)	10	304	262	3 (0.98%)	1 (0.38%)
Current study	2011	PFC®	APT2 70.1 (62–93) MBT 64.7	7	217	558	4 (1.8%)	0 (0%)

* Values are expressed as mean, with range in parentheses; MBT = modular metal-backed tibia; APT = all-polyethylene tibia; APT2 = all-polyethylene tibia after 1999.

care have increased [15, 16, 30]. The cost of the implant is the largest expense associated with TKA [15, 16, 23, 30]. APT implants offer an opportunity to control hospital costs for TKA while maintaining quality. APT implants in this study provided at least equivalent clinical outcomes over MBT implants in patients with a BMI of less than 37.5.

APT implants are equivalent to MBT implants when surgeons consider tibial component survivorship for cemented TKA in patients with a BMI of less than 37.5. This study demonstrated APT components, when utilized without regard for activity and age, were equivalent to MBT components in patients with a BMI of less than 37.5. In this study, patients with BMI of greater than 37.5, poor proximal tibial bone, or proximal tibial bone defects did not receive APT components. It remains to be seen whether APT components may be used successfully in the larger patient group. APT utilization also can be associated with a substantial reduction in primary TKA hospital cost in this age of healthcare reform and cost control [15, 26, 30].

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References

1. Apel DM, Tozzi JM, Dorr LD. Clinical comparison of all-polyethylene and metal-backed tibial components in total knee arthroplasty. *Clin Orthop Relat Res.* 1991;273:243–251.
2. Bargren JH, Blaha JD, Freeman MA. Alignment in total knee arthroplasty: correlated biomechanical and clinical observations. *Clin Orthop Relat Res.* 1983;173:178–183.
3. Bettinson KA, Pinder IM, Moran CG, Weir DJ, Lingard EA. All-polyethylene compared with metal-backed tibial components in total knee arthroplasty at ten years: a prospective, randomized controlled trial. *J Bone Joint Surg Am.* 2009;91:1587–1594.
4. Currier BH, Currier JH, Collier JP, Mayor MB. Effect of fabrication method and resin type on performance of tibial bearings. *J Biomed Mater Res.* 2000;53:143–151.
5. Dalury DF, Pomeroy DL, Gonzales RA, Gruen TA, Adams MJ, Empson JA. Midterm results of all-polyethylene tibial components in primary total knee arthroplasty. *J Arthroplasty.* 2009;24:620–624.
6. Dorr LD, Coanty JP, Shriber R. Technical factors that influence mechanical loosening of total knee arthroplasty. In: Dorr LD, ed. *The Knee Papers of the First Scientific Meeting of The Knee Society.* 3rd ed. Baltimore, MD: University Park Press; 1985:121.
7. Ducheyne P, Kagan A 2nd, Lacey JA. Failure of total knee arthroplasty due to loosening and deformation of the tibial component. *J Bone Joint Surg Am.* 1978;60:384–391.
8. Engh GA, Lounici S, Rao AR, Collier MB. In vivo deterioration of tibial baseplate locking mechanisms in contemporary modular total knee components. *J Bone Joint Surg Am.* 2001;83:1660–1665.
9. Evanski PM, Waugh TR, Orofino CF, Anzel SH. UCI knee replacement. *Clin Orthop Relat Res.* 1976;120:33–38.
10. Faris PM, Ritter MA, Keating EM, Meding JB, Harty LD. The AGC all-polyethylene tibial component: a ten-year clinical evaluation. *J Bone Joint Surg Am.* 2003;85:489–493.
11. Font-Rodriguez DE, Scuderi GR, Insall JN. Survivorship of cemented total knee arthroplasty. *Clin Orthop Relat Res.* 1997;345:79–86.
12. Freeman MA, Samuelson KM, Levack B, de Alencar PG. Knee arthroplasty at the London Hospital. *Clin Orthop Relat Res.* 1986;205:12–20.
13. Gioe TJ, Santos ER, Stroemer ES. All polyethylene and metal-backed tibias have similar outcomes at 10 years: a randomized, level 1 evidence study. *Clin Orthop Relat Res.* 2007;455:212–218.
14. Gioe TJ, Sinner P, Mehle S, Ma W, Killeen KK. Excellent survival of all-polyethylene tibial components in a community joint registry. *Clin Orthop Relat Res.* 2007;464:88–92.
15. Healy WL, Iorio R, Ko J, Appleby D, Lemos DW. Impact of cost reduction programs on short-term patient outcome and hospital cost of total knee arthroplasty. *J Bone Joint Surg Am.* 2002;84:348–353.
16. Healy WL, Iorio R, Lemos MJ, Patch D, Pfeifer BA, Smiley PM, Wilk RM. Single price/case price purchasing in orthopedic surgery: experience at the Lahey Clinic. *J Bone Joint Surg Am.* 2000;82:607–612.
17. Hirakawa K, Bauer TW, Yamaguchi M, Stulberg BN, Wilde AH. Relationship between wear debris particles and polyethylene surface damage in primary total knee arthroplasty. *J Arthroplasty.* 1999;14:165–171.
18. Insall J, Scott WN, Ranawat CS. The total condylar knee prosthesis: a report of two hundred and twenty cases. *J Bone Joint Surg Am.* 1979;61:173–180.
19. Iorio R, Healy WL, Kirven FM, Pfeifer B, Appleby DA. Knee implant standardization: an implant selection and cost reduction program. *Am J Knee Surg.* 1998;11:73–79.
20. 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;89:780–785.
21. Lewis JL, Askew MJ, Jaycox DP. A comparative evaluation of tibial component designs of total knee prostheses. *J Bone Joint Surg Am.* 1982;64:129–135.
22. L'Insalata J, Stern S, Insall J. Total knee arthroplasty in elderly patients: comparison of tibial component designs. *J Arthroplasty.* 1992;7:261–266.
23. Mendenhall S. Where are implant prices going? *Orthop Network News.* 1996;7:2–6.
24. Mikulak SA, Mahoney OM, dela Rosa MA, Schmalzried TP. Loosening and osteolysis with the press-fit condylar posterior-cruciate substituting total knee replacement. *J Bone Joint Surg Am.* 2001;83:398–403.
25. Muller SD, Deehan DJ, Holland JP, Outterside SE, Kirk LM, Gregg PJ, McCaskie AW. Should we reconsider all-polyethylene tibial implants in total knee replacement? *J Bone Joint Surg Br.* 2006;88:1596–1602.
26. Najibi S, Iorio R, Surdam JW, Whang W, Appleby D, Healy WL. All polyethylene and metal-backed tibial components in total knee arthroplasty: a matched pair analysis of functional outcome. *J Arthroplasty.* 2003;18:9–15.
27. O'Rourke MR, Callaghan JJ, Goetz DD, Sullivan PM, Johnston RC. Osteolysis associated with cemented modular posterior cruciate-substituting total knee design: five to eight-year follow-up. *J Bone Joint Surg Am.* 2002;84:1362–1371.
28. Pagnano MW, Levy BA, Berry DJ. Cemented all polyethylene tibial components in patients age 75 and older. *Clin Orthop Relat Res.* 1999;367:73–80.
29. Pomeroy DL, Schaper LA, Badenhausen WE, Suthers KE, Smith MW, Empson JA, Curry JJ. Results of all-polyethylene tibial components as a cost-saving technique. *Clin Orthop Relat Res.* 2000;380:140–143.
30. Rana A, Healy WL, Iorio R. Hospital economics of primary total knee arthroplasty at a teaching hospital. *Clin Orthop Relat Res.* 2011;469:87–94.
31. Ranawat CS, Boachie-Ajei O. Survivorship analysis and results of total condylar knee arthroplasty: eight to eleven year followup period. *Clin Orthop Relat Res.* 1988;226:6–13.

32. Rand JA. Comparison of metal-backed and all polyethylene tibial components in cruciate condylar total knee arthroplasty. *J Arthroplasty*. 1993;8:307–314.
33. Reilly D, Walker PS, Ben-Dov M, Ewald F. Effects of tibial components on load transfer in the upper tibia. *Clin Orthop Relat Res*. 1982;165:273–282.
34. Rodriguez JA, Baez N, Rashquinha V, Ranawat CS. Metal-backed and all-polyethylene tibial components in total knee replacement. *Clin Orthop Relat Res*. 2001;392:174–183.
35. Schai PA, Thornhill TS, Scott RD. Total knee arthroplasty with the PFC system: results at a minimum of ten years and survivorship analysis. *J Bone Joint Surg Am*. 1998;80:850–858.
36. Scuderi GR, Insall JN, Windsor RE, Moran MC. Survivorship of cemented knee replacements. *J Bone Joint Surg Br*. 1989;71:798–803.
37. Vince KG, Insall JN. Long-term results of cemented total knee arthroplasty. *Orthop Clin North Am*. 1988;19:575–580.
38. Walker PS, Greene D, Reilly D. Fixation of the tibial components of knee prosthesis. *J Bone Joint Surg Am*. 1981;63:258–268.
39. Walker PS, Ranawat CS, Insall J. Fixation of the tibial components of condylar knee prosthesis. *J Biomech*. 1976;9:269–275.