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Safety of orthopedic implants: implant migration analysis a must

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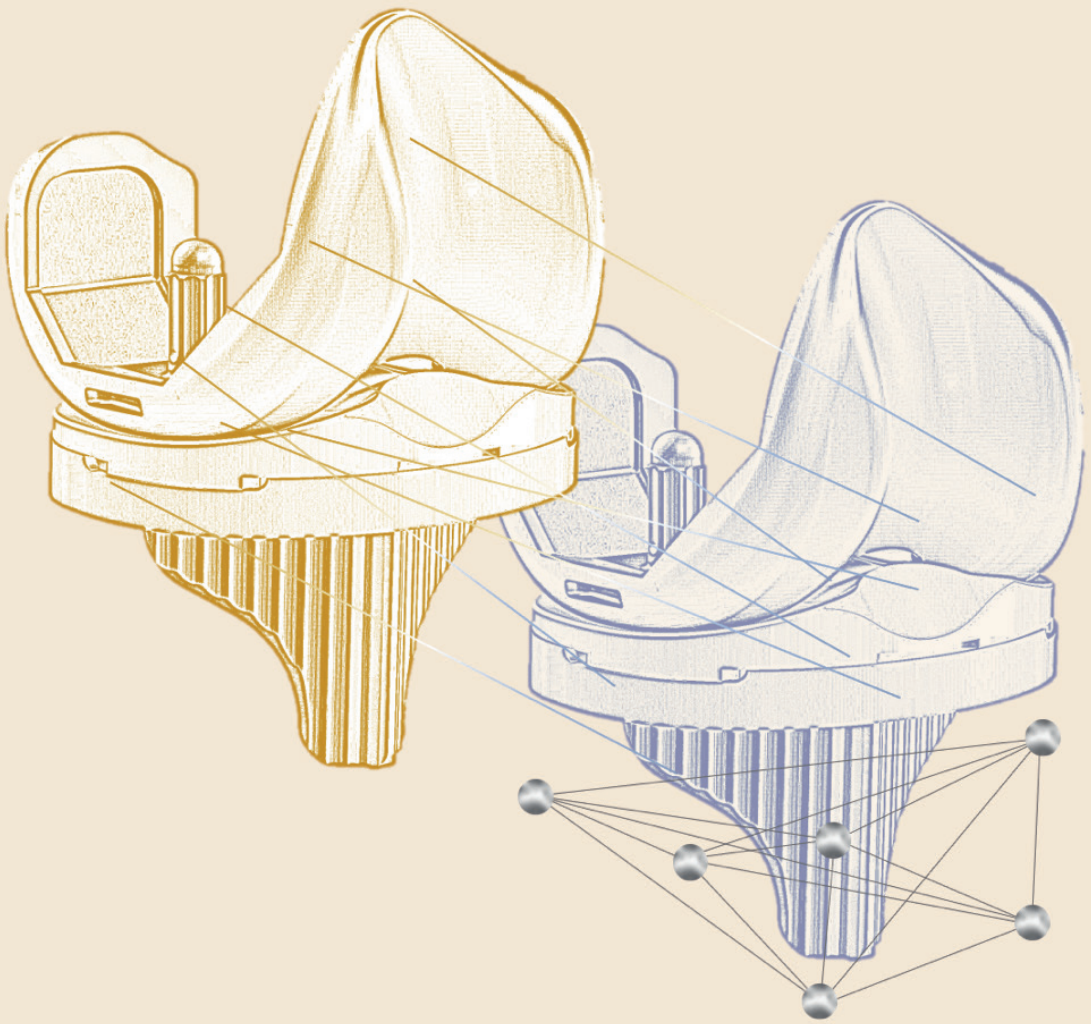
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Chapter IV

All-polyethylene versus metal-backed posterior stabilized total knee arthroplasty

Similar 2-year results of a randomized radiostereometric analysis study

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Abstract

Background and purpose

The all-polyethylene tibial (APT) component introduced in the early 1970's, was surpassed by the metal-backed tibial (MBT) trays as the first choice for total knee arthroplasty (TKA). With improved polyethylene, the modern APT components can reduce costs, and have shown equivalent results in survivorship and early migration of the cruciate retaining and cruciate stabilizing designs. This study compares the 2-year migration of a similarly designed APT-posterior stabilized (PS) and a MBT-PS TKA, using radiostereometric analysis (RSA).

Patients and methods

60 patients were randomized to receive either an APT Triathlon PS or a MBT Triathlon PS TKA (Stryker, NJ, USA). Migration measured by RSA and clinical scores were evaluated at baseline and at 3, 12, and 24 months postoperatively. Repeated measurements were analyzed with a linear mixed model and generalized estimating equations.

Results

The mean maximum total point movement (MTPM) at 3, 12, and 24 months was 0.41mm (95%CI 0.33-0.50), 0.57mm (CI 0.44-0.70) and 0.56mm (CI 0.42-0.69) respectively in the MBT group and 0.46mm (CI 0.36-0.57), 0.61mm (CI 0.49-0.73) and 0.64mm (CI 0.50-0.77) in the APT group. 2 MBT and 1 APT implant were considered unstable at 2-year follow-up. The KSS-Knee score and KSS-Function across 3, 12 and 24 months were comparable in both groups.

Interpretation

For an APT-PS designed component, MTPM measured with RSA is comparable to the MBT-PS component after 2-year of follow-up. No differences in complications or clinical outcomes were found.

Introduction

Despite many advantages of the all-polyethylene tibial (APT) component, like avoiding backside wear, preserving tibial bone and lower costs, it accounts for only 0.1-13% of the total knee arthroplasties (TKA) registered.^{1, 2} When TKA was introduced in the early 1970s, implants included APT components, but this design was soon replaced by a metal-backed tibial (MBT) component due to disappointing survival rates of the APT.^{3, 4} However, the APT is now regaining interest due to the higher costs of the MBT.^{5, 6} Furthermore, APT has comparable results to MBT.⁵ The advantage of the APT is that it preserves tibial bone as less resection is needed for the same polyethylene thickness, and that it avoids backside wear.^{4, 5, 7, 8}

Several studies have compared the outcomes of more recent APT designs with MBT in terms of survival, revision, and complications. Although reporting contradicting results, most studies found comparable survival rates of the APT and MBT.^{4, 7, 9-11} Radiostereometric analysis (RSA) objectively measures migration of a prosthesis and can predict revision for aseptic loosening after 2-year.^{12, 13} Few RSA studies comparing the APT and MBT have been conducted, showing less migration for the APT design in 1 study¹⁴, whilst others found no difference¹⁵⁻¹⁸, but these studies only included Cruciate Retaining (CR) or Condylar Stabilizing (CS) TKA and not Posterior Stabilizing (PS) TKAs. The use of PS designed TKAs varies and is particularly popular in the United States and the Netherlands where it comprises 49% and 56% of all TKAs used, respectively.^{19, 20} The cam-post design of a PS insert could cause additional stress on the tibial component compared to a CR design.^{21, 22} So apart from mixed results in studies with CR and CS designs, outcomes of these studies cannot be extrapolated to PS implants because of this cam-post design. A study comparing PS designed APT and MBT components is therefore needed.

Hence, we compared the migration of an APT- versus a MBT-PS designed prosthesis with up to 2-year follow-up using RSA.

Patients and methods

This study was a prospective, randomized RSA trial comparing the APT-PS Triathlon Total Knee System to the MBT-PS Triathlon (Stryker, Warsaw, USA). Between November 2014 and June 2015, 60 consecutive patients were included and randomized to either an APT-PS or a MBT-PS component at the Hässeholm Hospital (Sweden). A blocked, computer-generated randomization scheme with a 1:1 ratio was used for randomization with a block size of 20. Patients were blinded to the treatment allocation and remained blinded throughout the study. Surgery was performed by 2 orthopedic surgeons who opened sealed opaque envelopes on the day of surgery. Clinical scores were assessed by blinded physical therapists. Inclusion criteria were patients with a painful knee resulting from osteoarthritis who were scheduled to undergo primary total knee surgery and were willing to sign an Informed Patient Consent Form. Main exclusion criteria were BMI > 40, a flexion or varus/valgus contracture >15°, pre-operative knee score >70 and patients who could not make the follow-up visits because of living far away from the hospital.

Prosthesis and surgical procedure

The Triathlon APT is made from conventional polyethylene, sterilized with gamma radiation in vacuum and is packaged in Nitrogen gas (N₂Vac). The modular MBT component uses a highly cross-linked polyethylene insert (X₃, Stryker Orthopaedics, Mahwah, USA). Patients were operated in concordance with the surgical protocol using a midline incision and a medial parapatellar approach. No tourniquet was used. Smartset GHV bone cement (DePuy CMW, Blackpool, UK) was only applied to the tibial baseplate. Perioperatively, 8 well-scattered tantalum beads (ø 0.8 mm; RSA Biomedical, Umeå, Sweden) were inserted into the tibial bone as reference markers. 5 beads were inserted into the polyethylene insert of the MBT and on a similar position in the polyethylene of the APT. Patellae were reshaped. Postoperative regime included immediate full weight-bearing and there were no differences in postoperative treatment between both groups.

Outcome measures

Primary outcome measure was prosthetic migration after 2-year measured by RSA defined as the Maximum Total Point Movement (MTPM), which is the length of the translational vector of the marker with the greatest migration in translation or rotation along the transverse, longitudinal or sagittal axis. In concordance with the ISO 16087 Standard, migration of a left-sided patient will be transformed to match the data of a right-sided patient to enable comparison between patients.

Translations and rotations are expressed according to the right-hand screw rule.²³ RSA radiographs were taken with the patient in supine position and the knee in a calibration cage using a biplanar technique in a 90-degree angle (Cage 10, RSA Biomedical, Umeå, Sweden). Radiographs were taken within 1-2 days postoperatively and at 3, 12, and 24 months. The first postoperative examination was taken as reference for subsequent examinations. At 12 months, double measurements were made to determine the precision of the examination. As no migration is expected between these 2 examinations performed at the same point in time, any migration measured will be the measurement error. The precision is expressed as the standard deviation of these measurements. Marker-based analysis using the software Model-based RSA version 4.11 (RSAcore, Leiden, the Netherlands) was used. A mean error of rigid body fitting below 0.35 mm and a condition number below 120 were set as cut-off points. A marker configuration model was used if not enough markers were visible at any follow-up moment.²⁴ Individual prostheses were considered stable if the increase in MTPM between 1-and 2-year postoperative was ≤ 0.2 mm, and consequently any prosthesis with a MTPM increase of >0.2 mm was considered as at risk for loosening.¹²

Secondary outcome measures were the Knee Society Score (KSS), the Knee Osteoarthritis Outcome Score (KOOS) and the Forgotten Joint Score (FJS). The KSS and KOOS were measured pre-operatively and at 3, 12 and 24 months. The FJS was measured at 3, 12, and 24 months. All scores ranged from 0 to 100 with higher scores indicating better scores.

Sample size

Sample size was calculated assuming that a difference of 0.3 mm for translation and 0.25° for rotation would be clinically relevant. 17 patients were needed in each group with an alpha of 0.05 and a power of 0.80. Taking into account that patients with inappropriate marking of the prosthesis or tibial bone will be excluded as well as possible patients lost to follow up, 30 patients in each group were included.

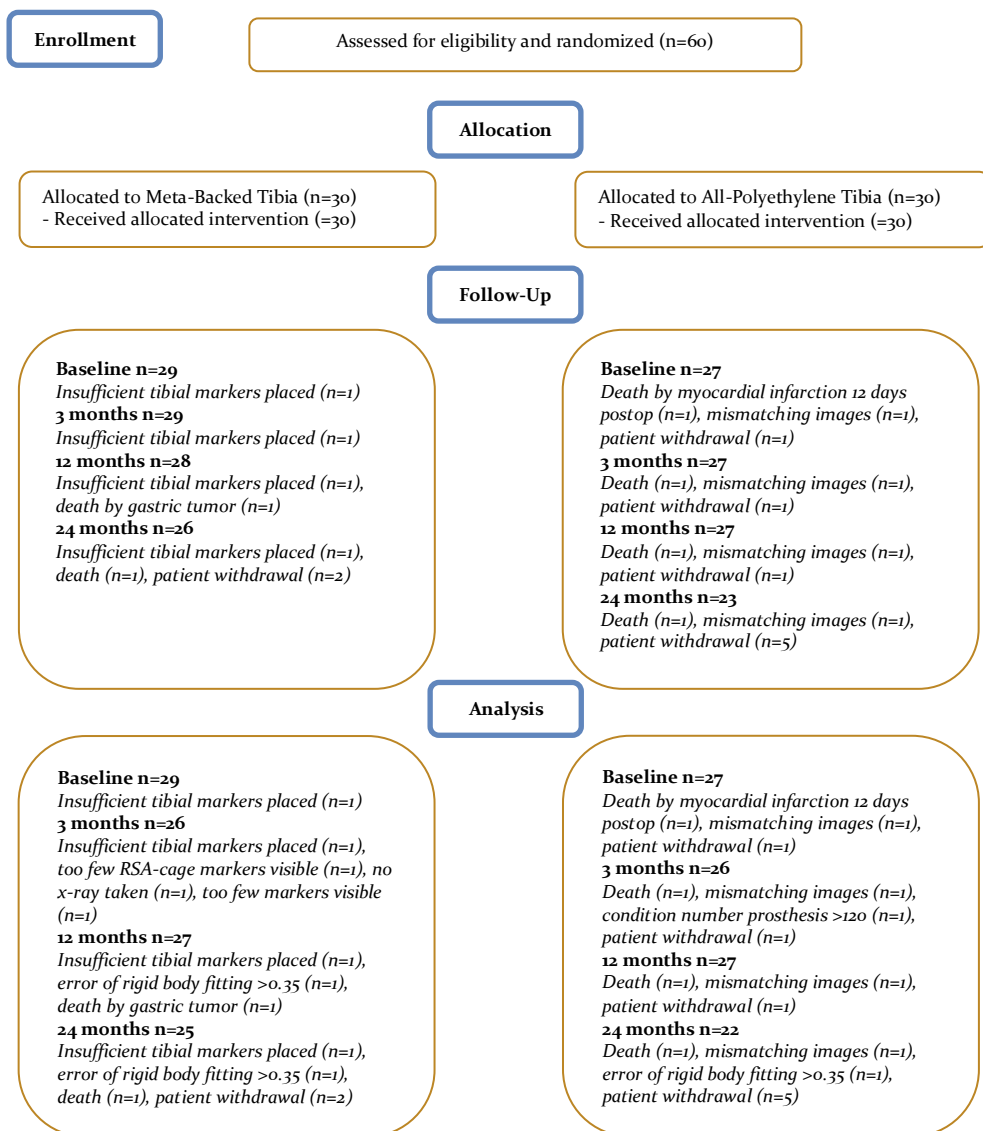
Statistics

Analyses were performed according to the intention-to-treat principle. MTPM, translations, rotations, and clinical outcome scores were analysed with a linear mixed model if normally distributed. This model is recommended to analyse repeated measurements as it takes the within-subject correlation as well as the missing values into account.²⁵ The model consisted of a group variable (APT versus MBT), a time variable (baseline, 3 months, 12 months, and 24 months) and an interaction term (fixed effects). An Auto-Regressive Order-1 covariance matrix was used to model remaining variability. The Generalised Estimating Equations (GEE) approach was used if a normal distribution could not be obtained through transformation. This approach was needed for the analysis of MTPM, the KSS-Knee score and the KOOS-Sports subscore. Mean translations and rotations are reported per group at 3, 12, and 24 months. Mean scores of the KSS-Knee, KSS-Function and the 5 subscales of the KOOS are reported per group preoperatively, and at 3, 12, and 24 months postoperatively. The mean FJS is reported at 3, 12, and 24 months postoperatively. P-values <0.05 were considered statistically significant. Means are reported with 95% confidence intervals (CI). Analyses were performed with SPSS version 23 (IBM SPSS Statistics 23.0; IBM Corp, Armonk, NY, USA).

Ethics, registration, funding, and potential conflicts of interest

Approval of the Regional Ethical Review Board in Lund was obtained before recruitment (entry no. 2014/513). This study was registered at the ISRCTN Registry (ISRCTN10744502) and was conducted in concordance with the CONSORT statement. All patients provided informed consent. Stryker funded this study but did not take any part in the design, conduct, analysis, and interpretations stated in this paper.

Figure IV.I CONSORT Flow Chart



Results

60 patients were included and randomized to either the APT-PS or the MBT-PS Total Knee Prosthesis. After randomization, 4 patients were excluded. 56 patients were thus included in the analysis [Figure IV.I]. During follow-up, 9 patients withdrew or had radiographs which could not be analyzed, leaving 47 patients for analysis at 2 years [Figure IV.I]. Age, BMI, sex, ASA score and Ahlbäck classification were similar at baseline. Each surgeon operated approximately half of the patients in both groups. Postoperatively, the MBT implants seemed to be more in varus compared to the APT [Table IV.I].

Table IV.I Baseline demographic characteristics

	Metal-Backed PS	All-Polyethylene	Total
Patients, n	29	27	56
Age, mean years (SD)	68 (4)	68 (4)	68 (4)
BMI, mean kg/m² (SD)	28 (4)	29 (3)	28 (3)
Sex, n			
Female	17	13	30
Male	12	14	26
ASA classification, n			
I	4	7	11
II	18	17	35
III	7	3	10
Surgeon, n			
#1	14	14	28
#2	15	13	28
Ahlbäck classification, n			
II	5	4	9
III	23	23	46
IV	1	0	1
HKA postoperative, n			
Varus (<177°)	7	3	10
Neutral (177-183°)	15	17	32
Valgus (>183°)	2	4	6
Missing*	5	3	8

SD = Standard Deviation, HKA = Hip-knee-ankle angle. * Some patients had no postoperative long-leg radiographs taken and HKA could not be assessed.

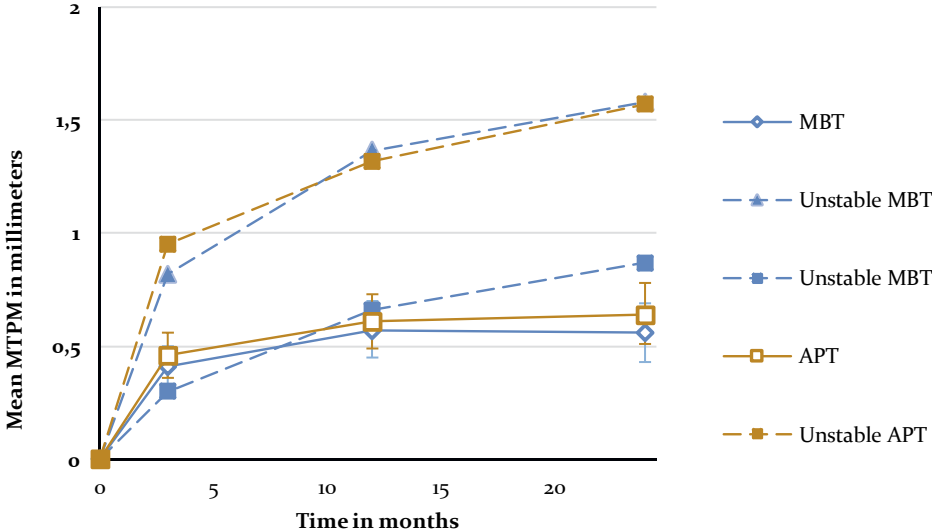
The mean MTPM across 3, 12, and 24 months was similar in both groups. The mean MTPM change from 12 to 24 months was -0.01 mm (CI -0.19; 0.17) in the MBT group and 0.03 (CI -0.14; 0.21) in APT group [Table IV.II; Figure IV.II]. Two implants in the MBT and 1 in the APT group displayed >0.2 mm MTPM between 1-and 2-year follow-up and were considered unstable [Figure IV.II]. The MBT group showed lift-off (positive), while the APT group showed tibial subsidence (negative) [Figure IV.III C]. A different migration pattern between the groups was also visible in the rotation along the longitudinal axis, being external (negative) in the MBT and internal (positive) in the APT group [Figure IV.III E]. Other translations and rotations were

Table IV.II Mean maximum total point motion of the metal-backed and all-polyethylene group with 95% confidence intervals (95%CI)

Time (months)	Metal-backed mean (95%CI)	All-polyethylene mean (95%CI)
3	0.41 (0.33-0.50)	0.46 (0.36-0.57)
12	0.57 (0.44-0.70)	0.61 (0.49-0.73)
24	0.56 (0.42-0.69)	0.64 (0.50-0.77)

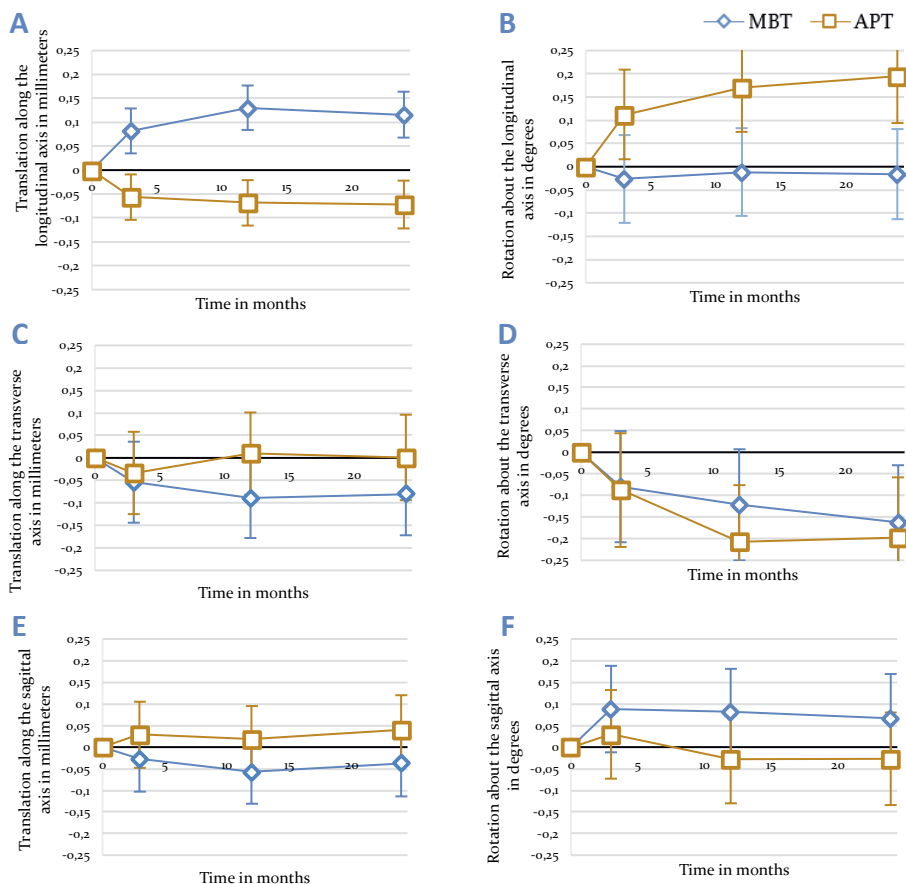
Figure IV.II Mean MTPM of the MBT and APT group with 95% CI over time. The MTPM of the 3 unstable implants are plotted and all 3 show continuous migration between 12 and 24 months follow-up.

MTPM: Maximum total point motion; MBT: metal-backed tibia; APT: all-polyethylene tibia



similar between groups with backward tilting (negative) being the most prominent direction of migration in both groups [Figure IV.III A,B, D, F]. None of the patients were scheduled for revision surgery. 50 double measurements were made at 1-year follow-up. The precision of the measurements of the translations and rotations were 0.1 mm and 0.1 degrees. The mean condition number of the tibial bone and the prosthesis was 42 (range 20-108) and 40 (range (21-114), respectively. The mean error of rigid body fitting was 0.14 (range 0.04-0.34) and 0.08 (range 0.01-0.47) of the tibial bone and the prosthesis, respectively.

Figure IV.III A-F Translation along and rotation about the transverse, longitudinal and sagittal axis. Means are represented with 95% confidence intervals (error bars).



The KSS-Knee scores across 3, 12, and 24 months were similar in both groups. KSS-Function score was also similar. Moreover, no statistically significant difference was found in the KOOS subscores or in the FJS [Table IV.III].

Table IV.III Clinical outcome scores with 95% confidence intervals [95%CI]

		Metal-backed	All-polyethylene
		Mean Score [95%CI]	Mean Score [95%CI]
KSS Knee	Preoperative	46 [43-50]	44 [42-46]
	3 months	93 [91-95]	86 [81-91]
	12 months	93 [90-96]	94 [90-97]
	24 months	98 [96-100]	95 [90-99]
KSS Function	Preoperative	54 [49-59]	52 [47-58]
	3 months	73 [68-78]	76 [71-82]
	12 months	85 [80-90]	85 [80-90]
	24 months	88 [83-93]	82 [77-88]
KOOS Symptoms	Preoperative	47 [41-53]	49 [42-55]
	3 months	67 [61-73]	62 [56-68]
	12 months	77 [71-83]	72 [66-79]
	24 months	80 [73-86]	75 [68-82]
KOOS Pain	Preoperative	38 [31-45]	41 [34-48]
	3 months	70 [63-77]	66 [59-73]
	12 months	82 [75-88]	80 [73-87]
	24 months	87 [80-94]	79 [72-86]
KOOS ADL	Preoperative	42 [35-48]	45 [38-52]
	3 months	75 [68-81]	67 [61-74]
	12 months	80 [73-86]	75 [68-82]
	24 months	82 [75-89]	75 [68-82]
KOOS Sports	Preoperative	9 [5-13]	12 [8-17]
	3 months	35 [26-44]	21 [14-29]
	12 months	42 [33-52]	40 [30-50]
	24 months	42 [35-50]	40 [29-50]
KOOS QoL	Preoperative	33 [27-38]	35 [30-40]
	3 months	46 [41-51]	43 [38-48]
	12 months	55 [50-60]	53 [48-58]
	24 months	54 [49-60]	53 [48-59]
FJS	3 months	36 [25-46]	35 [24-46]
	12 months	61 [50-72]	56 [45-67]
	24 months	58 [47-69]	51 [40-63]

KSS: Knee society score; KOOS: Knee osteoarthritis outcome score; ADL: Activities of daily living; QoL: Quality of Life; FJS: Forgotten joint score

Discussion

We found similar MTPM between the APT-PS and MBT-PS at 2-year follow-up, the translation and rotation along and about the 3 orthogonal axes were different for longitudinal translation and rotation. Van Hamersveld et al. (2018), who used a CS design, and other RSA studies on CR designs reported comparable MTPM values as in our study.¹⁴⁻¹⁸ These findings suggest that, although PS implants most likely experience different shear forces at the implant-bone interface, the MTPM values after 2-year follow-up are comparable to CR and CS designs. Furthermore, despite the relative elasticity of a full APT component, this did not result in a difference in migration compared to a MBT component. This may imply that the polyethylene insert within the metal baseplate gives enough peak stress absorption in the PS design. The difference in translation along the longitudinal axis was previously described by Adalberth et al. (2000) who compared a low-conforming APT and MBT with RSA and concluded that this finding might be explained by an increase in tensile forces in the less flexible MBT.^{15, 26} In our study, the subsidence of the APT and lift-off of the MBT stabilized after 3 months. The difference in rotation about the longitudinal axis (i.e. internal/external rotation) between the MBT and APT in our study might be due to unmeasured differences between the groups such as the alignment of the tibial component. Another explanation might be the minor differences in the postoperative HKA between groups, but the groups are too small to draw any valid conclusion. We reported signed migration values in contrast to several other RSA studies. In order to allow comparison between RSA studies and to understand the direction of migration, reporting signed values is preferred as was previously suggested by Valstar et al. (2005).²⁷

Gudnason et al. (2017) suggested that it was better to use the transversal rotation for analysis of RSA-migration data as it was a better predictor for aseptic loosening than MTPM. The rotation in the transverse plane was posterior for both groups (Figure 5, Rotation along the transverse axis).²⁸ The posterior rotation of the tibial implants in both groups could be due to anterior engagement of the cam-post mechanism of the

PS-design which engages in extension. Banks et al. (2002) found that TKAs are frequently aligned in relative hyperextension which might explain the rotation in the present study.²⁹ Another factor contributing to the posterior rotation might be the single radius design of the TKA used in our study which might play a role as the center of rotation lies more posteriorly compared to multi-radius designs.³⁰ Whether this migration pattern has clinical consequences remains unclear and should be studied further when longer follow-up data becomes available.

The KSS-Knee and -Function scores increased postoperatively and were comparable in both groups during follow-up, which is consistent with previous studies.^{15, 16} The KOOS subscales and the FJS also showed similar results. De Carvalho et al. (2013) used different clinical outcomes (the Oxford Knee Score, the Western Ontario and McMaster Universities Arthritis Index and the Short form-12 scores), but also found no difference between groups.³¹

Our study with an all-polyethylene PS design failed to show superiority of either APT nor MBT. Nevertheless, Chambers et al. (2016) estimated that a reduction of 42% in costs could be achieved if the APT were used.⁶ However, the actual costs of an implant differs widely and the total costs of TKA treatment consist of more than just the tibial component including personnel, equipment, and space costs. In addition, the financial benefit of the APT might not outweigh the limitations as it cannot be coated, and a liner exchange is not possible. These factors may be among the reasons why orthopedic surgeons continue to use the MBT TKA as the implant of first choice even though some suggest that the APT could be an acceptable treatment in patients above 70 years of age or with rheumatoid arthritis.³²

A limitation of this study is the lack of power to detect a difference in clinical scores between both groups. RSA studies, in general, include small groups and probably fail to detect any differences due to this small sample size. Including more patients, however, would nullify the strength of RSA studies as it can measure migration with high precision and, therefore, only a small sample size is needed to assess the

stability of implants. Another limitation is the difference in polyethylene as the polyethylene insert of the MBT tray was made of highly-crosslinked polyethylene and the APT was made from conventional polyethylene. Ideally, the polyethylene in both implants would be the same, but this was not possible due to manufacturing limitations.

In summary, the APT-PS TKA prosthesis has comparable migration as the MBT-PS TKA in terms of MTPM measured by RSA at 2-year of follow-up, even though there was a different pattern in longitudinal translation and rotation. No differences in complications or clinical outcomes were found between both groups.

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References

1. Norwegian Arthroplasty Register. Norwegian National Advisory Unit on Arthroplasty and Hip Fractures: 2018 Annual Report. Available from: http://nrlweb.ihelse.net/eng/Rapporter/Report2018_english.pdf. Accessed on July 17, 2018.
2. SKAR, Swedish Knee Arthroplasty Register. Annual Report 2018. Available from: http://www.myknee.se/pdf/SVK_2018_Eng_1.0.pdf. Accessed on 08-02-2019.
3. Steinberg DR, Steinberg ME. The early history of arthroplasty in the United States. *Clin Orthop Relat Res*. 2000(374):55-89.
4. Browne JA, Gall Sims SE, Giuseffi SA, Trousdale RT. All-polyethylene tibial components in modern total knee arthroplasty. *J Am Acad Orthop Surg*. 2011 19(9):527-35.
5. Gioe TJ, Maheshwari AV. The all-polyethylene tibial component in primary total knee arthroplasty. *J Bone Joint Surg Am*. 2010 92(2):478-87 DOI: 10.2106/jbjs.i.00842.
6. Chambers MC, El-Othmani MM, Sayeed Z, Anoushiravani A, Schnur AK, Mihalko WM, et al. Economics of All-Polyethylene Versus Metal-Backed Tibial Prosthesis Designs. *Orthopedics*. 2016 39(3 Suppl):S61-6 DOI: 10.3928/01477447-20160509-18.
7. Cheng T, Pan X, Liu T, Zhang X. Tibial component designs in primary total knee arthroplasty: should we reconsider all-polyethylene component? *Knee Surg Sports Traumatol Arthrosc*. 2012 20(8):1438-49 DOI: 10.1007/s00167-011-1682-y.
8. Gustke KA, Gelbke MK. All-Polyethylene Tibial Component Use for Elderly, Low-Demand Total Knee Arthroplasty Patients. *J Arthroplasty*. 2017 32(8):2421-2426 DOI: 10.1016/j.arth.2017.02.077.
9. Nouta KA, Verra WC, Pijls BG, Schoones JW, Nelissen RG. All-polyethylene tibial components are equal to metal-backed components: systematic review and meta-regression. *Clin Orthop Relat Res*. 2012 470(12):3549-59 DOI: 10.1007/s11999-012-2582-2.
10. Voss B, El-Othmani MM, Schnur AK, Botchway A, Mihalko WM, Saleh KJ. A Meta-Analysis Comparing All-Polyethylene Tibial Component to Metal-Backed Tibial Component in Total Knee Arthroplasty: Assessing Survivorship and Functional Outcomes. *J Arthroplasty*. 2016 31(11):2628-2636 DOI: 10.1016/j.arth.2015.08.035.
11. Longo UG, Ciuffreda M, D'Andrea V, Mannering N, Locher J, Denaro V. All-polyethylene versus metal-backed tibial component in total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc*. 2017 25(11):3620-3636 DOI: 10.1007/s00167-016-4168-0.
12. Ryd L, Albrektsson BE, Carlsson L, Dansgard F, Herberts P, Lindstrand A, et al. Roentgen stereophotogrammetric analysis as a predictor of mechanical loosening of knee prostheses. *J Bone Joint Surg Br*. 1995 77(3):377-83.
13. Pijls BG, Valstar ER, Nouta KA, Plevier JW, Fiocco M, Middeldorp S, et al. Early migration of tibial components is associated with late revision: a systematic review and meta-analysis of 21,000 knee arthroplasties. *Acta Orthop*. 2012 83(6):614-24 DOI: 10.3109/17453674.2012.747052.
14. Van Hamersveld KT, Marang-Van De Mheen PJ, Nelissen R, Toksvig-Larsen S. Migration of all-polyethylene compared with metal-backed tibial components in cemented total knee arthroplasty. *Acta Orthop*. 2018:1-6 DOI: 10.1080/17453674.2018.1464317.
15. Adalberth G, Nilsson KG, Bystrom S, Kolstad K, Milbrink J. Low-conforming all-polyethylene tibial component not inferior to metal-backed component in cemented total knee arthroplasty: prospective, randomized radiostereometric analysis study of the AGC total knee prosthesis. *J Arthroplasty*. 2000 15(6):783-92.
16. Adalberth G, Nilsson KG, Bystrom S, Kolstad K, Milbrink J. All-polyethylene versus metal-backed and stemmed tibial components in cemented total knee arthroplasty. A prospective, randomised

- RSA study. *J Bone Joint Surg Br.* 2001 83(6):825-31.
17. Norgren B, Dalen T, Nilsson KG. All-poly tibial component better than metal-backed: a randomized RSA study. *Knee.* 2004 11(3):189-96 DOI: 10.1016/s0968-0160(03)00071-1.
 18. Hyldahl H, Regner L, Carlsson L, Karrholm J, Weidenhielm L. All-polyethylene vs. metal-backed tibial component in total knee arthroplasty—a randomized RSA study comparing early fixation of horizontally and completely cemented tibial components: part 2. Completely cemented components: MB not superior to AP components. *Acta Orthop.* 2005 76(6):778-84 DOI: 10.1080/17453670510045363.
 19. AAOS, American Academy of Orthopaedic Surgeons. Fifth AJRR Annual Report on Hip and Knee Arthroplasty Data. Available from: http://ajrr.net/images/annual_reports/AOS-AJRR-2018-Annual-Report-final.pdf?hsCtaTracking=c794b145-8b50-405a-af5c-666a0841a730%07C6996bb53-5b74-4d65-bb51-b24f37c55c9d. Accessed on 08-02-2019.
 20. LROI, Dutch Arthroplasty Register. Online LROI annual report 2018. Available from: http://www.lroi-rapportage.nl/media/pdf/PDF%20Online_LROI_annual_report_2018.pdf. Accessed on 08-02-2019.
 21. Garling EH, Valstar ER, Nelissen RG. Comparison of micromotion in mobile bearing and posterior stabilized total knee prostheses: a randomized RSA study of 40 knees followed for 2 years. *Acta Orthop.* 2005 76(3):353-61.
 22. Molt M, Toksvig-Larsen S. Similar early migration when comparing CR and PS in Triathlon TKA: A prospective randomised RSA trial. *Knee.* 2014 21(5):949-54 DOI: 10.1016/j.knee.2014.05.012.
 23. ISO16087:2013(E). Implants for surgery: Roentgen stereophotogrammetric analysis for the assessment of migration of orthopaedic implants. Geneva, Switzerland: International Organization for Standardization. 2013.
 24. Kaptein BL, Valstar ER, Stoel BC, Rozing PM, Reiber JH. A new type of model-based Roentgen stereophotogrammetric analysis for solving the occluded marker problem. *J Biomech.* 2005 38(11):2330-4 DOI: 10.1016/j.jbiomech.2004.09.018.
 25. Ranstam J, Turkiewicz A, Boonen S, Van Meirhaeghe J, Bastian L, Wardlaw D. Alternative analyses for handling incomplete follow-up in the intention-to-treat analysis: the randomized controlled trial of balloon kyphoplasty versus non-surgical care for vertebral compression fracture (FREE). *BMC Med Res Methodol.* 2012 12:35 DOI: 10.1186/1471-2288-12-35.
 26. Bartel DL, Burstein AH, Santavicca EA, Insall JN. Performance of the tibial component in total knee replacement. *J Bone Joint Surg Am.* 1982 64(7):1026-33.
 27. Valstar ER, Gill R, Ryd L, Flivik G, Borlin N, Karrholm J. Guidelines for standardization of radiostereometry (RSA) of implants. *Acta Orthop.* 2005 76(4):563-72 DOI: 10.1080/17453670510041574.
 28. Gudnason A, Adalberth G, Nilsson KG, Hailer NP. Tibial component rotation around the transverse axis measured by radiostereometry predicts aseptic loosening better than maximal total point motion. *Acta Orthop.* 2017 88(3):282-287 DOI: 10.1080/17453674.2017.1297001.
 29. Banks SA, Harman MK, Hodge WA. Mechanism of anterior impingement damage in total knee arthroplasty. *J Bone Joint Surg Am.* 2002 84-A Suppl 2:37-42 DOI: 10.2106/00004623-200200002-00004.
 30. D'Lima DD, Poole C, Chadha H, Hermida JC, Mahar A, Colwell CW, Jr. Quadriceps moment arm and quadriceps forces after total knee arthroplasty. *Clin Orthop Relat Res.* 2001(392):213-20 DOI: 10.1097/00003086-200111000-00026.
 31. De Carvalho BR, Yassaie OS, Muir DC. Modular versus all-polyethylene tibial components: comparison of pre- and early post-operative patient scores in total knee replacement. *ANZ J Surg.* 2013 83(10):784-7 DOI: 10.1111/ans.12270.
 32. Nouta KA, Pijls BG, Nelissen RG. All-polyethylene tibial components in TKA in rheumatoid arthritis: a 25-year follow-up study. *Int Orthop.* 2012 36(3):565-70 DOI: 10.1007/s00264-011-1341-4.