# Gap patterns and radiographic follow-up of newer-generation cementless total knee arthroplasty designs

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**Background:** Interest in cementless total knee arthroplasty (TKA) has increased with advancement of biomaterials and implant design and associated improved longevity. We sought to evaluate the gap patterns and radiolucent zones radiographically for 2 newer-generation cementless TKA designs.

**Methods:** We retrospectively reviewed our single-institution database between January 2017 and December 2019. We identified patients with a porous keeled tibia baseplate with 4-bullet cruciform spikes and peri-apatite coated femoral component (study group 1) and patients who received a cementless porous coated femoral component and rotating platform tibia baseplate with 4 peripheral porous coated pegs around a central cone (study group 2). We identified gap patterns at 6 weeks and at 1 year or more postoperatively on radiographs, noting indications for reoperation.

**Results:** We identified 228 patients in study group 1 and 41 patients in study group 2. At 1-year follow-up, we found evidence of resolved femoral gaps in 52 (72.2%) of 72 patients in study group 1 and 10 (58.8%) of 17 patients in study group 2 ($p = 0.124$). We identified 27 (84.3%) of 32 patients in study group 1 and 7 (70.0%) of 10 patients in study group 2 with resolved tibia gaps ($p = 0.313$). After 1 year, there were significantly more Zone 3a femoral zonal radiolucent gaps ($p = 0.001$) and Zone 8 tibia zonal radiolucent gaps ($p = 0.002$) in study group 2 than in study group 1. There were 4 reoperations for study group 1 and 0 reoperations for study group 2.

**Conclusion:** The modern cementless TKA systems have varied gap patterns in postoperative radiographs, which may be attributed to the implant design. Most radiolucent gaps resolve radiographically on follow-up.

**Contexte :** Les percées dans les biomatériaux et la conception des prothèses, associées à une longévité accrue de ces dernières, ont entraîné un regain d'intérêt pour l'arthroplastie totale du genou (ATG) non cimentée. Nous avons cherché à évaluer par radiographie les espaces et les zones radiotransparentes pour 2 ATG de nouvelle génération sans ciment.

**Méthodes :** Nous avons rétrospectivement passé en revue notre base de données (un seul établissement) pour la période de janvier 2017 à décembre 2019. Nous y avons repéré les patients ayant reçu une pièce tibiale poreuse à quille avec 4 pointes cruciformes et une composante fémorale à revêtement de peri-apatite (groupe 1) et les patients ayant reçu une composante fémorale poreuse revêtue non cimentée et une pièce tibiale en rotation avec 4 plots périphériques poreux revêtus autour d'un cône central (groupe 2). Six semaines puis au moins 1 an après l'intervention, nous avons identifié sur des radiographies les espaces en notant les indications de réintervention.

**Résultats :** Nous avons étudié 228 patients dans le groupe 1 et 41 patients dans le groupe 2. Au suivi après 1 an, nous avons trouvé des signes d'espace fémoral résorbé chez 52 patients sur 72 (72,2 %) du groupe 1 et chez 10 patients sur 17 (58,8 %) du groupe 2 ($p = 0{,}124$). Nous avons trouvé chez 27 patients sur 32 (84,3 %) du groupe 1 et 7 patients sur 10 (70,0 %) du groupe 2 un espace tibial résorbé ($p = 0{,}313$). Après 1 an, il y avait considérablement plus d'espaces radiotransparents dans la zone fémorale 3a ($p = 0{,}001$) et d'espaces radiotransparents dans la zone tibiale 8 ($p = 0{,}002$) dans le groupe 2 que dans le groupe 1. Il y a eu 4 réinterventions dans le groupe 1 et aucune dans le groupe 2.

**Conclusion :** Les systèmes d'ATG modernes sans ciment présentent des espaces variés sur les radiographies postopératoires, ce qui peut être attribué à la conception de la prothèse. La plupart des espaces radiotransparents se sont résorbés à la radiographie de suivi.

Knee end-stage osteoarthritis is successfully treated with total knee arthroplasty (TKA), with more than 55 000 TKA procedures performed in Canada in 2020–2021 alone.[1] Cemented TKA is typically preferred for this procedure, given that cementless designs historically showed high rates of aseptic loosening of the tibia component, as well as inferior survivorship.[2–4] Recently, interest in cementless TKA has increased, especially when considering the treatment of patients with obesity or younger, active patients. In these patients, cemented designs may not provide long-term fixation, and cementless designs have fewer systemic complications associated with cement impaction.[5,6] The most recent data have shown that patients younger than 55 years who have undergone cemented TKA have a 16.6% chance of having their TKAs revised after 20 years.[7] Cemented designs in these patients have a risk of long-term failures from the sheer forces at the bone–cement interface, leading to a combination of micromotion, aseptic loosening, and osteolysis.[8] Studies that have investigated cementless designs have seen promising results, with cementless designs having equal or better survivorship and clinical efficacy as their cemented counterparts.[9–13] These improvements are thought to be owing to better biomaterials, and highly crosslinked polyethylene, as well as postoperative bony ingrowth.[9,14,15] Current designs are now incorporating additive manufacturing techniques, with porous shape titanium or tantalum.[16,17]

As cementless TKA is being more widely considered as an implant option for patients, it is important to evaluate if they will offer an advantage in terms of postoperative radiographic survival. Identifying and measuring gap patterns and radiolucent zones radiographically may serve as a method to predict long-term postoperative survivorship of a cementless TKA implant. These radiolucent zones are posited to be a sign of aseptic loosening, with the notion that fewer gaps suggest superior bone–implant interface and improved survivorship.[18,19] Accurate bone cuts are necessary for success in TKA to ensure appropriate contact between metal and bone, given that malalignment has been identified as a cause of failure.[20,21] Newer cementless TKA designs have shown promising results on early postoperative follow-up.[22,23]

Previous biomechanical studies have highlighted the impact of different design features of cementless tibial trays on micromotion and their potential effects on bony ingrowth, although how these differences translate clinically and radiographically in the short postoperative period is less understood.[24–26] We sought to evaluate and compare the gap patterns and radiolucent zones radiographically for 2 newer-generation cementless TKA designs.

## Methods

We retrospectively reviewed our prospectively collected data from between January 2017 and December 2019 for 2 different systems of newer-generation cementless TKA implants that were implanted by 3 fellowship-trained arthroplasty surgeons at our centre. The decision to have these patients receive cementless fixation was based on a variety of factors, including patient age, preoperative radiographs, and intraoperative bony assessment. Ultimately, the final decision for cementless fixation was made by the consultant surgeon. All TKAs were for patients with diagnoses of primary osteoarthritis. Age and body mass index were not used as exclusionary criteria.

In terms of surgical technique, a standard medial parapatellar approach was used. The implantation was done using standard manual or conventional techniques, with cutting jigs and blocks. Careful attention was paid to flexion and extension spaces, using either gap balancing or measured resection technique. The patellas were not resurfaced. The goal was to obtain neutral mechanical alignment. All patients were immediately weight-bearing as tolerated subsequent to the procedure and were on appropriate deep vein thrombosis prophylaxis.

Upon research ethics committee approval, we searched our institutional arthroplasty registry for all patients who underwent TKA with 1 of 2 different systems of cementless TKA implants. All implants used were of cruciate retaining design. For study group 1, we identified patients who received the Triathlon system (Stryker Orthopaedics). This TKA system is a highly porous, tritanium-keeled tibia baseplate with 4-bullet cruciform spikes and a beaded periapatite-coated femoral component. The survivability of this implant in the short postoperative period has been shown in several studies.[23,27] For study group 2, we identified patients who received the Attune system (DePuy Synthes). This TKA system is a cementless porous coating (Porocoat), femoral component and rotating platform tibia baseplate with 4 peripheral, porous-coated pegs around a proximally coated central cone. The survivorship for this specific implant under cementless conditions is being investigated.[28] Of note, the Attune implant was designed to allow additional clearance at the chamfer cuts, particularly the anterior chamfer, to ensure the final implant seats fully on the distal femur and to permit the surgeon to adjust the anterior position of the femoral component by 1.5 mm in either direction.[29]

In our study, we compared the gap patterns (i.e., radiolucent zones) of the femoral and tibial components 6 weeks and at least 1 after surgery using postoperative radiographs. Radiographs were done using standardized protocol by the same technicians. Standing anterior–posterior and lateral, as well as sunrise, radiographic views were included, analyzed by 2 authors (J.L. and A.F.).

### *Data analysis*

We used the intraclass correlation coefficient of random 10% sample of the data set to determine observer agreement.

**Table 1. Radiolucent lines of the femoral component at 6 weeks and 1 year or more after total knee arthroplasty**

| | 6-wk radiographs | | | 1-yr radiographs | | |
|---|---|---|---|---|---|---|
| Zone | No. (%) of group 1 patients *n* = 228 | No. (%) of group 2 patients *n* = 41 | *p* value | No. (%) of group 1 patients *n* = 228 | No. (%) of group 2 patients *n* = 41 | *p* value |
| 1 | 12 (5.3) | 0 (0.0) | 0.134 | 7 (3.1) | 1 (2.4) | 0.826 |
| 2 | 8 (3.5) | 3 (7.3) | 0.258 | 4 (1.8) | 1 (2.4) | 0.764 |
| 3a | 33 (14.5) | 14 (34.1) | 0.002 | 15 (6.6) | 9 (22) | 0.001 |
| 3 | 37 (16.2) | 9 (22) | 0.368 | 6 (2.6) | 3 (7.3) | 0.124 |
| 3p | 6 (2.6) | 2 (4.9) | 0.435 | 0 (0.0) | 0 (0.0) | – |
| 4 | 1 (0.4) | 0 (0.0) | 0.674 | 1 (0.4) | 0 (0.0) | 0.674 |
| 5 | 0 (0.0) | 0 (0.0) | – | 0 (0.0) | 0 (0.0) | – |

**Table 2. Radiolucent lines of the tibial component at 6 weeks and 1 year or more after total knee arthroplasty**

| | 6-wk radiographs | | | 1-yr radiographs | | |
|---|---|---|---|---|---|---|
| Zone | No. (%) of group 1 patients *n* = 228 | No. (%) of group 2 patients *n* = 41 | *p* value | No. (%) of group 1 patients *n* = 228 | No. (%) of group 2 patients *n* = 41 | *p* value |
| 1 | 8 (3.5) | 3 (7.3) | 0.258 | 3 (1.3) | 1 (2.4) | 0.582 |
| 2 | 0 (0.0) | 1 (2.4) | 0.18 | 0 (0.0) | 0 (0.0) | – |
| 3 | 0 (0.0) | 0 (0.0) | – | 0 (0.0) | 0 (0.0) | – |
| 4 | 11 (4.8) | 1 (2.4) | 0.496 | 3 (1.3) | 0 (0.0) | 0.459 |
| 5 | 0 (0.0) | 0 (0.0) | – | 0 (0.0) | 0 (0.0) | – |
| 6 | 0 (0.0) | 0 (0.0) | – | 0 (0.0) | 0 (0.0) | – |
| 7 | 0 (0.0) | 0 (0.0) | – | 0 (0.0) | 0 (0.0) | – |
| 8 | 11 (4.8) | 5 (12.1) | 0.065 | 3 (1.3) | 4 (9.8) | 0.002 |
| 9a | 1 (0.4) | 0 (0.0) | 0.674 | 0 (0.0) | 0 (0.0) | – |
| 9b | 0 (0.0) | 0 (0.0) | – | 0 (0.0) | 0 (0.0) | – |
| 9c | 1 (0.4) | 0 (0.0) | 0.674 | 0 (0.0) | 0 (0.0) | – |
| 10 | 15 (6.6) | 6 (14.6) | 0.077 | 5 (2.2) | 3 (7.3) | 0.075 |

The gap patterns and radiolucency of the TKA were assessed using the zonal classification system of modern Knee Society Radiographic Evaluation.[30] We defined radiolucent gaps as lucent areas (≤ 2 mm) between the implant and bone that can be identified on normal radiographs. We also evaluated for any failures or indications for reoperations. We calculated relative percentages for each zone, and used a z-score test to calculate *p* values.

We analyzed data was using SPSS, considering *p* values less than 0.05 significant.

### *Ethics approval*

This study was approved by the Lawson Health Research Institute (no. R-22-005) and Western University Research Ethics Board (no. 120247).

## Results

We identified 228 patients in group 1 and 41 patients in group 2. The mean age was 63.9 (standard deviation [SD] 7.6) years in group 1 and 64.3 (SD 7.9) years in group 2 ($p = 0.78$). The mean body mass index was 33.6 (SD 7.2) in group 1 and 33.3 (SD 7.3) in group 2 ($p = 0.79$). The mean time to the 1-year radiograph was 13.8 (SD 0.60) months for group 1 and 13.5 (SD 1.4) months for group 2 ($p = 0.63$). The intraclass correlation coefficient was 0.82. The femur and tibia zonal radiolucent lines were assessed for the 2 systems at 6 weeks and 1 year or more after TKA (Table 1 and Table 2).

At the 6-weeks follow-up, 72 (31.6%) patients in group 1 had radiolucent gaps (≤ 2 mm) at the femoral component and 32 (14.0%) patients had radiolucent gaps at the tibial component. In group 2, 17 (41.5%) patients had radiolucent gaps at the femoral component and 10 (24.4%) patients had radiolucent gaps at the tibial component. At the 1-year follow-up, most radiolucent gaps had bony ingrowth and radiolucent gaps or lines in both the study groups had resolved. We observed resolved femoral gaps in 52 (72.2%) patients in group 1 and 10 (58.8%) patients in group 2 ($p = 0.124$). Twenty-seven (84.3%) patients in group 1 and 7 (70.0%) patients in group 2 had resolved tibia gaps ($p = 0.313$). Thus, 20 (27.8%) patients in group 1 and 7 (41.2%) patients in group 2 had unresolved gaps at the femoral component;

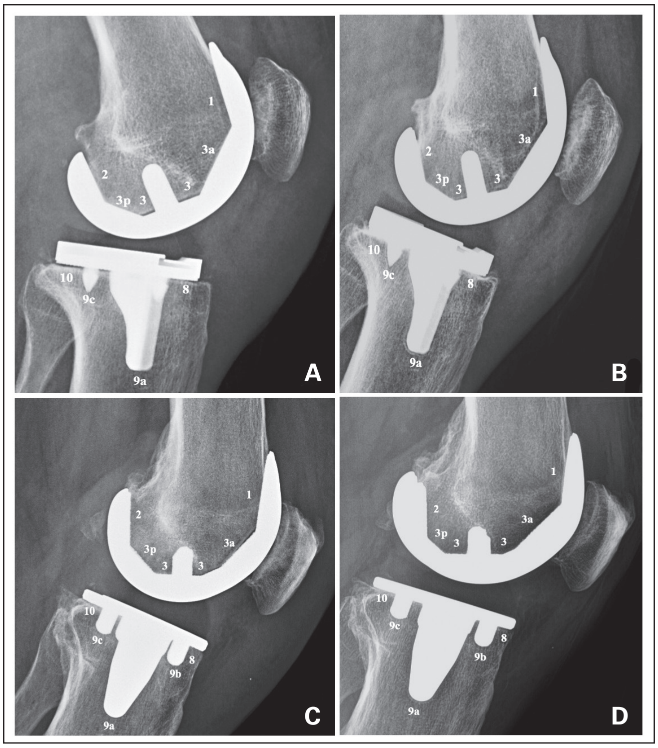


**Fig. 1.** Lateral radiographs at postoperative follow-up 6 weeks and 1 year or more after cementless total knee arthroplasty (TKA). (A) A patient who received the Triathlon system had visible gaps at 6 weeks, which filled by the (B) 1-year follow-up. We observed the same trends at (C) 6-week and (D) 1-year follow-up in a patient who received an Attune TKA. Zones are labelled according to the zonal classification system of modern Knee Society Radiographic Evaluation.[30]

5 (15.7%) patients in group 1 and 3 (30.0%) patients in group 2 had unresolved gaps at the tibial component. Group 2 had significantly more Zone 3a femoral radiolucent gaps ($p$ = 0.001) and Zone 8 tibia radiolucent gaps ($p$ = 0.002) than group 1 at 1-year postoperative radiographic follow-up. These radiolucent gaps are qualitatively expressed in Figure 1, showing 1 patient from each group after 6 weeks and at least 1 year postoperatively. For both patients, the notable radiolucent gaps at 6 weeks filled with bone after 1 year.

There were zero reoperations for group 2 and 4 reoperations for group 1. Three complications consisted of 2 prosthetic joint infections, managed with débridement, antibiotics, and implant retention, and 1 patella maltracking diagnosis, managed with secondary patella resurfacing. One patient had possible aseptic tibial tray loosening and this implant was revised. The patient had severe pain for at least a year after the initial TKA. The 1-year postoperative radiographs did not show signs of loosening, gapping, or osteolysis. A bone scan showed increased activity under the medial tibial base plate and over the lateral femoral condyle. She received a revision procedure and her pain ultimately resolved. There were no indications of loosening or substantial bone loss noted intraoperatively.

## Discussion

With the availability of modern cementless designs with some encouraging early results, there has been a paradigm shift and renewed interest in cementless TKA. Older cementless implants had important design concerns, specifically at the tibial base plate and metal-backed patellas, which increased the risks of aseptic loosening, an unwelcome complication associated with TKA.[2–4] Modern manufacturing processes have changed the porosity and design elements of current cementless systems, which seem to have addressed the earlier concerns. By achieving predictable osseous integration, biologic fixation may be a preferable method to use in patients with obesity and younger patients, in comparison to cement fixation.[9,11,15] Although previous studies have shown equivalent survivorship and clinical outcomes between cementless and cemented TKA, continued observation and analysis of cementless TKA is essential to mitigate implant failure.[3,10–12,23]

Radiolucent zones are often used as early indicators for aseptic loosening for TKAs.[18,19] The clinical importance of these radiolucent zones is not well understood, especially in the context of different and newer-generation TKA implants. We sought to investigate these gaps at 6 weeks and at least 1 year postoperative follow-ups, in 2 different implant types. We found that most radiolucent gaps at the femoral and tibial components, regardless of the specific implant used, resolved with bony ingrowth. The proportion of patients with resolved femoral and tibial gaps did not significantly differ between study groups. Most gaps were located at the chamfer cuts (Zones 3a/3p) and at the most anterior and posterior aspects of the tibial tray (Zone 4 and 10). In addition, revisions were uncommon, with 1.75% of implants being revised in group 1 and no patients requiring revision in group 2. These results are in agreement with the few studies in the literature that have analyzed radiolucent zones in cementless TKA.[29,30]

One of the earliest studies on gap patterns in cementless TKA was done by Costales and colleagues[31] in 2020; they investigated 21 patients (26 knees) with a cruciate-retaining, cementless, porous-coated femur with mobile tibial tray and crosslinked polyethylene over a 9-year period, which is a different TKA design from those used in the current study.[31] Although radiolucencies or gaps were common, these gaps were small (< 2 mm), did not progress, and did not have any association with long-term functional outcomes. In fact, their patients had excellent clinical outcome scores, with no revisions required. These authors offered a similar conclusion — that many gaps resolve 1 year after implantation. A 2002 multicentre study by Desmerais and colleagues[32] looked at radiolucent zones in 277 patients who received the same implants as those in our study group 2 (Attune), over a 2-year period. This retrospective study showed that 25% of their cohort had radiolucent gaps. Interestingly, most gaps were seen under the tibial base plate. Femoral gaps were uncommon and all of them resolved. Despite the presence of these radiolucencies, clinical outcomes were excellent after 2 years, demonstrating a lack of association between the gap patterns and clinical outcomes or failure.

As we compared 2 distinct cementless implants, there were differences in specific radiolucent zones. After both time points, group 2 had a significantly greater proportion of gaps at the anterior chamfer (Zone 3a) than group 1. This difference is likely owing to implant design. The Attune implant was designed to allow additional clearance at the chamfer cuts, particularly the anterior chamfer, to ensure that the final implant seats fully on the distal femur.[29] Although a significant difference remained after 1 year, in each patient group, the gaps resolved with bony ingrowth. The only other radiolucent zone with marked difference in proportions was Zone 8, where a greater proportion of patients in group 2 had a gap than group 1 after 1 year. The reason for this difference is not entirely clear. It is possible that gaps in the first group resolved with bony ingrowth more quickly than those in the second group. It is also likely that the anterior portion of the tibial baseplate was not fully seated when initially implanted. The study by Desmerais and colleagues[32] noted that radiolucencies were more frequent at the tibial base plate in this exact design, without further commentary on possible explanations. More follow-up is required of this cohort to determine if bony ingrowth occurs in this zone.

### *Limitations*

Since this study was retrospective in nature, we could not always obtain true lateral or anterior–posterior images. Although a standardized imaging protocol, carried out by the same technicians, was used for all patients, in some instances, the radiographs were rotated, making interpretation of radiolucent gaps or bony ingrowth challenging. Another critique is our difference in sample size by implant type, with 228 patients in group 1 and 41 patients in group 2. At our institution, the Triathlon implant has been available for a longer period than the Attune implant, resulting in increased implantation of the Triathlon. The proportions of gaps in the radiolucent zones, however, were comparable. Lastly, although most radiolucent gaps did fill with bone, we were only able to follow-up with patients 1 year after surgery. Continuing to follow both patient groups would be valuable in understanding the relationship between radiographical and functional outcomes, including survivorship and patient-reported outcome measures, in future comparative studies.

### *Conclusion*

We compared radiolucent gaps of 2 cementless TKA implants. The modern cementless TKA systems have varied gap patterns in the postoperative radiographs, which may be attributed to the implant design. Most radiolucent gaps in our series resolved on subsequent radiographic follow-up. There were no significant adverse effects or early aseptic loosening owing to the gaps in the short-term follow-up in our study.

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**Competing interests:** Matthew Teeter sits on boards with the International Society for Technology in Arthroplasty, Canadian Orthopaedic Research Society, and Canadian Radio Stereometric Analysis (RSA) Network. James Howard reports funding from DePuy, and honoraria, consulting fees, or travel support from Stryker, Smith and Nephew, DePuy, Intellijoint, Zimmer, and Sanofi. He sits on boards with Intellijoint and AO Recon North America. Edward Vasarhelyi reports research support from Microport, DePuy, Smith and Nephew, Stryker, Zimmer, and Biomet; consulting fees from DePuy, Zimmer, Biomet, and MicroPort; honoraria from AO Recon North America; participation on monitoring boards with Hip Innovation Technology; and Canadian RSA Network membership. Brent Lanting reports research support or consulting fees from Smith and Nephew, DePuy, Zimmer, and Stryker. No other competing interests were declared.

**Contributors:** Matthew Teeter and Brent Lanting contributed to the conception and design of the work. Abigail Frazer and Edward Vasarhelyi contributed to data acquisition. James Howard and Jason Lim contributed to data analysis and interpretation. Abigail Frazer and Jason Lim drafted the manuscript. All of the authors revised it critically for important intellectual content, gave final approval of the version to be published, and agreed to be accountable for all aspects of the work.



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