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# Effect of Tobacco Use on Radiolucent Lines in Modern Cementless Total Knee Arthroplasty Tibial Components

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ABSTRACT

*Background:* The link between tobacco consumption and wound complications following total knee arthroplasty (TKA) is well established. However, the effect of tobacco use on biologic fixation in cementless TKA remains unknown. This study evaluated the influence of tobacco use on the presence of radiolucent lines of tibial components in cementless TKA.

*Methods:* A total of 293 consecutive cementless TKAs of 2 contemporary designs were retrospectively reviewed. Tibial radiolucent lines and component alignment were measured using an established measurement protocol. Patients with any history of tobacco use or active tobacco use (tobacco users) were compared to those with no history of tobacco use (tobacco nonusers). No significant differences which influenced outcomes were detected between the tobacco user and tobacco nonuser groups ($P \geq .071$).

*Results:* Radiolucent lines decreased from 1-month to latest follow-up (mean 2.5 years) in all 10 radiographic zones regardless of tobacco use ($P \leq .084$). However, evaluating *intrapatient* change in radiolucent line width, the tobacco nonuser group had more radiolucent lines resolve by the latest follow-up in nearly all radiographic zones, although most differences did not reach statistical significance, except for anteroposterior zone 1 (−31% vs −19%, $P = .022$). No tibial components were revised for aseptic loosening.

*Conclusions:* Results from this study suggest that any tobacco use prior to cementless TKA has the potential to hinder biologic fixation of tibial components. While no tibial components were revised for aseptic loosening, follow-up was relatively short at 2.5 years and therefore warrants further study to discern the effect of persistent radiolucent lines on long-term fixation.

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## Introduction

Total knee arthroplasty (TKA) reliably reduces pain and restores function in patients with symptomatic knee osteoarthritis [1,2]. The optimal mode of fixation in TKA has been a subject of debate for decades. Proponents of cemented TKA cite good to great survivorship and clinical outcomes [3–8]. However, while polymethylmethacrylate bone cement provides excellent initial fixation, the durability of cemented TKA remains a concern with aseptic loosening being the most common indication for revision [9–13]. Furthermore, as the prevalence of TKA increases with an aging population, epidemiologic studies predict up to a 601% increase in revision TKA by 2030 [14].

There has been a substantial increase in cementless fixation for TKA since 2012 in the United States. Approximately 14% of all primary TKAs in 2020 were reported to be cementless according to the 2021 American Joint Replacement Registry [15]. Cementless fixation offers the potential for osseous integration, which may increase implant longevity and thus reduce the burden of revision TKA due to aseptic loosening [16–19]. Historically, previous cementless TKA designs resulted in early failure though some

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designs have demonstrated excellent revision free survivorship at 20 years when excluding failures of metal-backed patellae [3,20]. With advances in prosthetic design, instrumentation, operative technique, and the emergence of highly porous metals for fixation, recent studies report encouraging results with modern cementless TKA designs [7,21–27]. Furthermore, recent data support lower early rates of aseptic loosening in patients who undergo cementless TKA compared to cemented TKA [21,25,26,28,29].

While tobacco usage is declining compared to previous years, a recent study reported that approximately 1 in 5 adults in the United States still use tobacco products [30]. Tobacco usage is a modifiable risk factor in arthroplasty that has been shown to increase risk of aseptic loosening and osteolysis in cemented TKA and increase aseptic loosening in total hip arthroplasty [22,31–33]. Additionally, tobacco usage in patients who undergo total joint arthroplasty results in increased rates of periprosthetic joint infection, readmission, postoperative complications, all-cause revision, and reoperation [34–36]. However, the effect of tobacco usage on osseointegration in modern cementless TKA designs currently remains unknown.

The purpose of this study was to evaluate the role of tobacco usage on radiographic and clinical fixation in cementless TKA using modern highly porous titanium tibial components and contemporary surgical techniques. We hypothesized that tobacco usage would be associated with increased radiographic lucencies with diminished resolution over time in these highly porous titanium tibial components.

## Material and methods

Upon institutional review board approval, a retrospective review was conducted on 293 patients who underwent cementless primary TKA by a single fellowship-trained arthroplasty surgeon between July 1, 2013, and December 30, 2019. Chart review in the electronic medical record was performed to obtain study variables: medical comorbidities, tobacco usage, tobacco use cessation, demographic variables, and radiographic data at 1-month and latest follow-up. Six cases were excluded: lack of 1-month baseline radiographs (n = 1) and suboptimal radiograph quality of the tibial component (n = 5), leaving 287 TKAs available for analysis.

There were 116 women (40.4%) and 171 men (59.6%). Fifty-six percent of cases were American Society of Anesthesiologists Physical Status classification I or II. Mean age and body mass index of the cohort were 56.6 years (range 34.7-75.9) and 35.5 kg/m$^2$ (range 21.3-53.2), respectively. The mean radiographic follow-up was 2.5 years (range 1.0-8.5). Mean anteroposterior (AP) tibial component alignment at 1 month postoperatively was 1.2 (standard deviation 1.9) degrees varus and mean posterior tibial slope was 5.6 (standard deviation 2.4) degrees. History of tobacco usage was determined by patient self-reported intake of cigarettes or smokeless tobacco during the preoperative clinic visit. These data were recorded as “no history of tobacco usage,” “past tobacco usage with cessation,” or “active tobacco usage.” There were 168 patients (59%) who reported no history of tobacco usage (tobacco nonuser group). Eighty-nine (31%) patients reported a history of tobacco usage with cessation, and 30 (11%) patients reported active tobacco usage at the time of surgery. Thus, there was a total of 119 patients (41%) who reported past or current tobacco use (tobacco user group, See Table 1).

There were no significant differences between tobacco nonuser and tobacco user groups in terms of age, years of follow-up; postoperative AP or lateral implant alignment; and indication for TKA, rheumatoid arthritis, psoriatic arthritis, systemic lupus erythematosus, or fibromyalgia (See Table 1, $P \geq .090$). There was also no significant difference in implant selection between the study groups ($P = .614$). The tobacco nonuser group had a significantly higher proportion of cases with American Society of Anesthesiologists Physical Status classification of I or II (64% vs 46%), significantly more women (48% vs 29%), and significantly lower mean body mass index (34.6 vs 36.8 kg/m$^2$) compared to the tobacco user group (See Table 1, $P \leq .005$). However, American Society of Anesthesiologists Physical Status classification, patient sex, and body mass index did not significantly influence the presence or resolution of tibial radiolucent lines in analysis ($P \geq .071$). Furthermore, for some comparisons with *P*-values considered trending (between 0.05 and 0.100), there was a large overlap in 95% confidence intervals further suggesting there was no significant difference between study groups.

### *Implant design and surgical technique*

Two cementless TKA designs (Implant A, EMPOWR Porous Knee; Enovis, Wilmington, Delaware or Implant B, Triathlon Tritanium; Stryker, Mahwah, New Jersey) were included in this study. Both designs consisted of a tibial baseplate with a highly porous titanium ingrowth surface, a robust central keel, 4 peripheral cruciform pegs and a porous cobalt-chromium femoral component, one with a highly porous 3-dimensional cobalt-chrome matrix surface (Implant A femur) and the other with a hydroxyapatite coating (Implant B femur).

A medial parapatellar approach was used for all procedures. Standard coronal plane femoral bone cuts were made with

**Table 1**
Cohort comparisons by tobacco use study groups.

| Variable | Tobacco users[a] | Tobacco non-users | Statistic | *P*-value |
|---|---|---|---|---|
| N | 119 | 168 | - | - |
| Mean age, y | 57 | 56 | 0.86 | .392 |
| Mean BMI, kg/m$^2$ | 37 | 35 | 2.84 | **.005**[b] |
| Follow up (y) | 1.7 | 1.7 | 0.25 | .803 |
| Sex, % women | 29% | 48% | 10.2 | **.002**[b] |
| ASA-PS, % I or II | 46% | 64% | 8.65 | **.004**[b] |
| Mean AP tibial alignment, deg | 89 | 89 | 1.7 | .090 |
| Mean posterior tibial slope, deg | 84 | 85 | 0.26 | .793 |
| Rheumatoid arthritis | 3% | 1% | 0.72 | .652 |
| Psoriatic arthritis | 0% | 1% | 0.71 | 1.000 |
| Fibromyalgia | 2% | 2% | 0.004 | 1.000 |
| Systemic lupus erythematosus | 0% | 1% | 1.42 | 1.000 |
| Implant, % implant A | 32% | 35% | 0.316 | .614 |

N, sample size; BMI, body mass index; ASA-PS, American Society of Anesthesiologists Physical Status classification; AP, anteroposterior.
Bold P-values indicate statistical significance.
[a] Tobacco users were defined as those with any history of tobacco use or those actively using tobacco products.
[b] While a significant difference was observed between study groups, these variables did not influence the presence or resolution of radiolucent lines on the tibial component.

computer-aided navigation (Stryker Navigation, Kalamazoo, Michigan), and tibial cuts were performed using an extramedullary cutting guide. A trial tibial baseplate (without the keel or pegs) was placed on the cut tibial surface. The flatness of the tibial cut was assessed by the "4-corner test" popularized by Dr. Leo Whiteside where an axial force was applied to all 4 quadrants. If the trial baseplate elevated at a region opposite any quadrant of applied force, the tibial cut flatness was corrected to ensure that no baseplate elevation occurred with a distally directed axial force on each of the 4 tibial quadrants. Knees were balanced within 1mm of laxity in the medial and lateral compartments with varus and valgus stress in flexion and extension as measured with calibrated lamina spreaders. Preparation of the tibial keel and cruciform pegs were performed with an intentionally designed press-fit utilizing a keel prep of interference fit with pilot drill holes for the cruciform pegs. The final tibial implant was impacted ensuring that the tibial baseplate and tibial bone cut surfaces were coplanar throughout impaction until fully seated to ensure an optimized interference-fit of the tibial keel and 4 cruciform pegs was achieved. The same modern perioperative pain control, clinical, and rehabilitation protocols were used for all patients.

*Clinical and radiographic outcomes*

Radiolucency data and tibial component alignment were evaluated at the 1-month and latest radiographic follow-up on AP and lateral view radiographs (See Fig. 1). Radiographic zones and alignment protocols of the tibial component were defined according to the modern Knee Society Radiographic Evaluation System [37]. Radiographic measurements were performed by 2 independent blinded raters. A standardized protocol was used for obtaining radiographs which prioritized having the x-ray beam collinear to the tibial baseplate. Radiolucent line ratings which differed categorically were revisited by a third rater and resolved. Tibial alignment measurements that differed by more than 5 degrees were revisited by a third rater and resolved. The 2 ratings were then averaged for a final tibial alignment value for analysis. Final rater agreement for categorical classification of radiolucent lines was 100% and tibial alignment rater agreement was 100% within 3 degrees.

*Data analyses*

All statistical analyses were performed in Minitab 21 (State College, Pennsylvania). Outliers were assessed with Dixon's r22 ratio tests due to group sample sizes exceeding 14. Normality of continuous data was evaluated with Anderson-Darling tests. Normally distributed continuous data are reported as means (standard deviation) and non-normally distributed data are reported as medians (interquartile range Q1, Q3). Means of 2 groups were compared with Student's 2 sample t-tests (t) and medians of 2 groups were compared with Mann-Whitney tests adjusted for ties (W). Categorical data are presented as percentages (%). Group proportions were evaluated with *chi*-square tests ($X^2$) and Fisher's exact test *P*-values for 2 $\times$ 2 contingency tables. Correlations between 2 continuous variables were evaluated with Spearman correlation tests (rho). An alpha level of 0.05 was considered statistically significant.

Statistical power was moderate ([1-β] $\leq$ 63.1%) given the group sample sizes and proportional group differences; however, group confidence intervals for significant differences had very little, if any, overlap suggesting a true significant difference limiting type I and type II errors, which is shown to be a more valid method for determining significant and non-significant findings rather than *P*-values alone [38–42].

## Results

A total of 182 cases achieved the minimum 1-year radiographic follow-up. At mean follow-up of 2.5 years (range 1.0-8.5), the

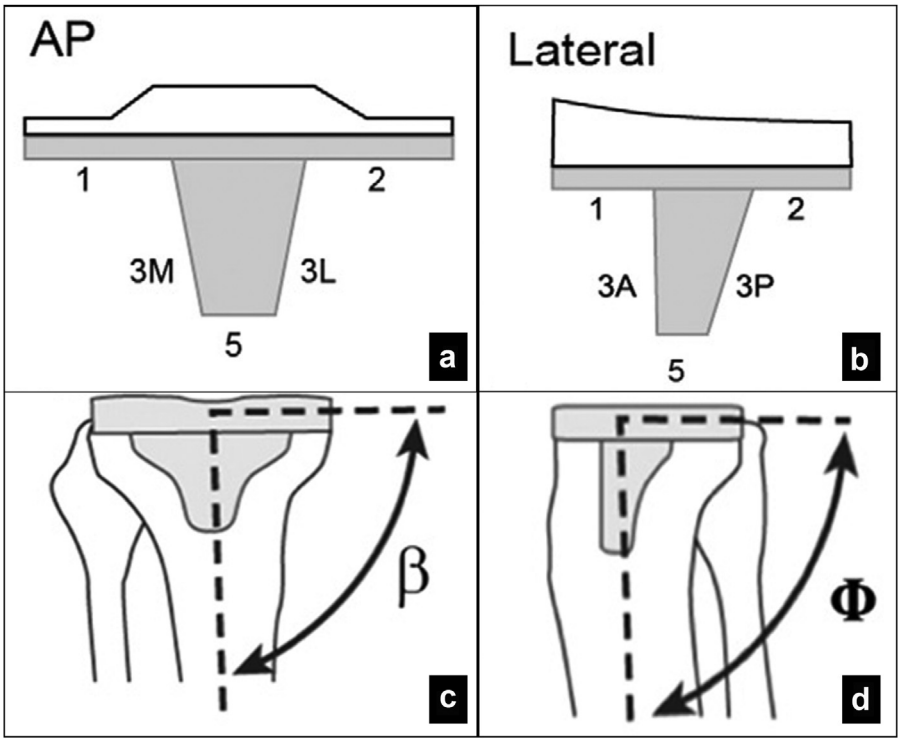


**Figure 1.** The radiographic zones used to evaluate radiolucent lines on the (a) anteroposterior and (b) lateral view x-rays. Tibial component alignment measurements for (c) AP alignment (β) and (d) posterior tibial slope (Φ) measurements. The zones and measurements are defined according the modern Knee Society Radiographic Evaluation System. AP, anteroposterior.

presence of radiolucent lines in all AP radiographic zones significantly decreased from the 1-month to latest radiographic follow-up (See Fig. 2, $P \leq .004$). Specifically, the presence of radiolucent lines decreased from 46% to 20% in zone 1, 37% to 7% in zone 2, 4% to 0% in zones 3M and 3L, and 11% to 2% in zone 5. 99.6% of all radiolucent lines were nonexistent or considered "partial" in width and all were <1mm in depth for all AP radiographic zones at the latest follow-up (See Fig. 3). There were no radiolucent lines in 80.2%, 92.9%, 100%, 100%, and 98.3% of patents in AP zones 1-5, respectively, at latest follow-up (See Fig. 3).

The presence of radiolucent lines in lateral radiographic zones 1, 2, 3A, and 3P significantly decreased from the 1-month to latest radiographic follow-up (See Fig. 4, $P \leq .084$). The presence of radiolucent lines in lateral zone 5 also decreased but did not reach statistical significance ($P = .084$). Specifically, the presence of radiolucent lines decreased from 40% to 13% in zone 1, 26% to 2% in zone 2, 5% to 2% in zone 3A, 6% to 0% in zone 3P, and 18% to 9% in zone 5. 99.6% of all radiolucent lines were nonexistent or considered "partial" in width and all were <1mm in depth for all lateral radiographic zones at latest radiographic follow-up (See Fig. 5). There were no radiolucent lines in 86.7%, 98.2%, 98.2%, 100%, and 90.9% in lateral zones 1-5, respectively, at the latest follow-up (See Fig. 5).

The proportion of radiolucent lines present at 1 month that resolved partially or completely by the latest follow-up was greater in nearly all 10 AP and lateral radiographic zones for the tobacco nonuser group compared to the tobacco user group (See Figs. 6 and 7). While the majority of differences did not reach statistical significance, the tobacco nonuser group consistently had more radiolucent lines resolve, and a significantly higher resolution of radiolucent lines in AP zone 1 compared to the tobacco user group (See Fig. 6; 31% vs 19%, $P = .022$).

Six cases required a reoperation. There were 2 femoral components revised for aseptic loosening at 6.6 and 11.5 months, 2 cases requiring polyethylene exchange for early polyethylene wear at 66.6 and 72.0 months, 1 revision for global instability and progressive patellar arthritis at 26.4 months, and 1 revision due to suspected nickel allergy and metal hypersensitivity at 13.3 months. No tibial components were revised for aseptic loosening. There was no difference in the rate of reoperation comparing tobacco nonuser with tobacco user study groups ($P = .406$).

## Discussion

The negative effects of tobacco use in total joint arthroplasty are well described. Kapadia et al. [31] demonstrated revision rates of 10% in tobacco users vs 1% in patients with no history of tobacco use. Lim et al. [43] showed that current smokers have an increased risk of earlier time to revision compared to nonsmokers and patients with a history of smoking. Similarly, the current study showed that tobacco users had lower resolution of radiolucent lines and presumably osseointegration at the tibial implant surface compared to tobacco non-users. This trend may represent a diminished biologic response for tobacco users in cementless TKA. In addition, Duchman et al. [35], in a robust analysis of 78,191 arthroplasty patients, demonstrated an increased risk of wound complications in current smokers compared to nonsmokers and previous smokers (odds ratio 1.5). Current and previous smokers also were at an increased risk of total complications (odds ratio range 1.18-1.20) [35]. Another study of 7,926 primary arthroplasty patients resulted in current tobacco users having higher hazard ratios for deep infection (hazard ratio 2.37) and implant revision (hazard ratio 1.78) than tobacco non-users [44]. The increased risk of septic complications is likely linked to the vasoconstrictive properties of nicotine and the diminished oxygen-carrying capacity secondary to elevated levels of carboxyhemoglobin. Together, these lead to diminished perfusion and a hypoxic environment in local tissue [32,35,43,45]. In terms of bone biology, tobacco use has repeatedly shown increased fracture nonunion, pseudoarthrosis rates following spinal fusion, and aseptic loosening in total hip arthroplasty and cemented TKA [32,44–47]. Additionally, in preclinical animal studies, nicotine administration was shown to reduce osseointegration into porous-titanium and hydroxyapatite implants [48,49] which is supported by the clinical evidence of the current study. Tobacco users were observed to have less overall resolution of radiolucent lines on the tibial implant-bone interface therefore potentially hindering osseointegration. Despite this finding, no tibial components were revised due to aseptic loosening which may suggest the enhanced ingrowth surface of the highly porous titanium tibial implant is somewhat protective in terms of osseointegration regardless of tobacco usage.

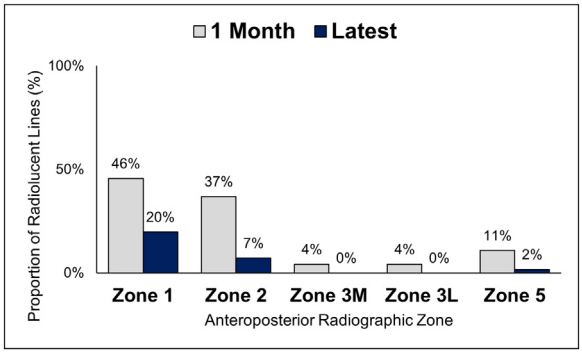


**Figure 2.** Significant decreases in the presence of radiolucent lines were observed from 1-month to latest follow-up for all AP zones. AP, anteroposterior.

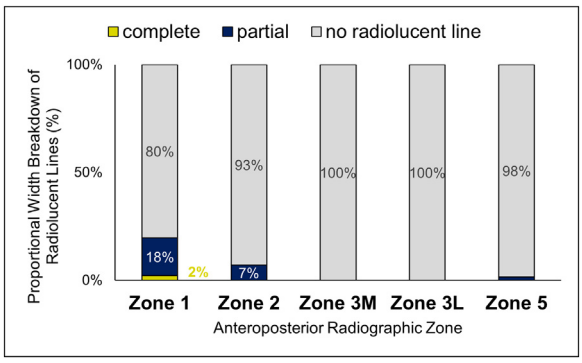


**Figure 3.** The majority of radiolucent lines in all AP radiographic zones at latest follow-up were nonexistent or classified as partial. AP, anteroposterior.

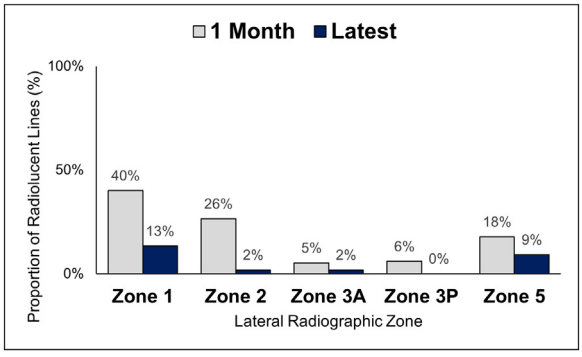


**Figure 4.** Significant decreases in the presence of radiolucent lines were observed from 1-month to latest follow-up for all lateral zones except for Zone 5, which decreased but did not reach statistical significance ($P = .084$).

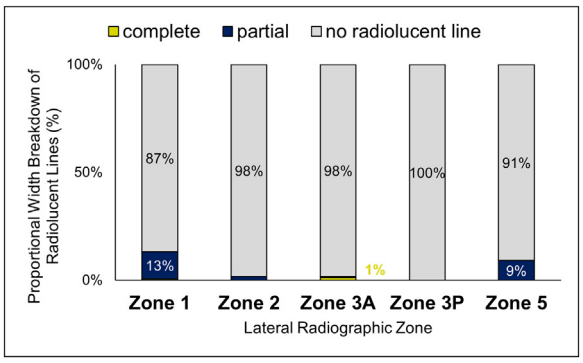


**Figure 5.** The majority of radiolucent lines in all lateral radiographic zones at latest follow-up were nonexistent or classified as partial.

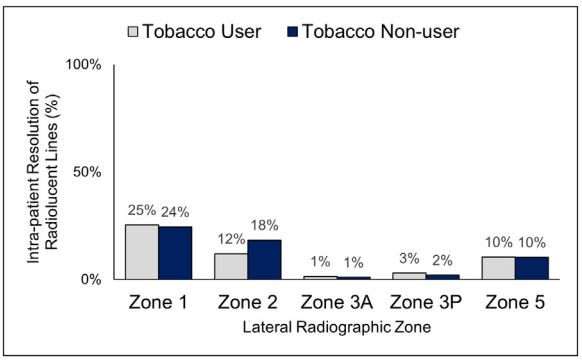


**Figure 7.** The tobacco nonuser group experienced essentially equivalent or greater resolution of radiolucent lines in all lateral radiographic zones from 1-month to latest follow-up compared to the tobacco user group; however, no group differences reached statistical significance.

Furthermore, contemporary implant designs with highly porous biomaterials have led to excellent survivorship of a select few historical designs and modern cementless TKA designs [20,25,29]. After removing failures due to metal-backed patellae, Ritter and Meneghini [20] demonstrated 97% survivorship of anatomic graduated cementless TKAs out to 20 years. Additionally, multiple randomized controlled trials comparing cemented to cementless TKA have shown no difference in revision rates at early follow-up [21,27]. In a matched comparison among morbidly obese patients undergoing TKA, cementless fixation demonstrated significantly lower rates of aseptic loosening at minimum 5-year follow-up [29]. Recently, there have been investigations into the role of biologic fixation of cementless TKA in patients over 75 years of age. In a propensity-matched cohort study comparing cemented to cementless TKA patients over 75 years of age, there was no difference in Knee Injury and Osteoarthritis Outcome Score for Joint Replacement or Short Form-12 final postoperative scores or improvement scores at 2 years [25]. Furthermore, survivorship free from aseptic revision was not different between cemented and cementless cohorts (99% vs 100%) at mean follow-up of 4.2 years (range 2.0-7.9) [25]. Despite the expanding interest for indications of cementless TKA, there remains a paucity of data on the effect of tobacco usage on biologic fixation in cementless TKA.

The current study had limitations. First, this study was a retrospective review of a single surgeon series from a single center which may limit external validity of study findings. However, the consistent implant designs and identical operative technique of this single-surgeon series may limit variability that a multi-surgeon study may not be able to overcome. Second, 105 patients lacked radiographic follow-up beyond 1 year, leaving 182 TKAs with complete radiographic data. Third, there was potential for measurement error with evaluating radiolucencies on plain radiographs which is dependent on the quality of the radiographs. Fourth, only tibial components were evaluated in this study due to the complexity of measuring radiolucencies on femoral components secondary to rotational obstruction of the implant-bone interface. Fifth, the clinical relevance of these study findings is currently unknown, as there was no difference in revision rates between study groups, particularly for aseptic loosening. Sixth, these study results are pertinent to the cementless tibial designs used in this study only, and caution should be used before assuming all cementless tibial components have equivalent performance. Lastly, history of tobacco use was dependent on patient self-reporting to the perioperative medical specialist prior to surgery which may introduce a reporting bias.

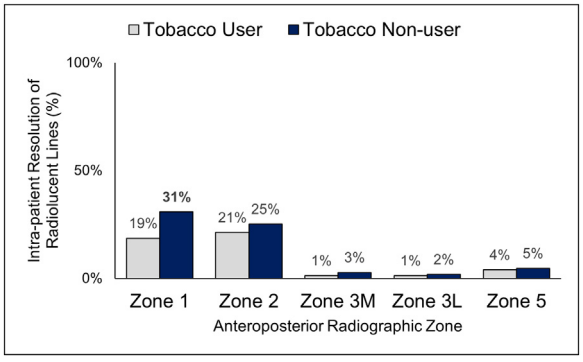


**Figure 6.** The tobacco non-user group experienced greater resolution of radiolucent lines in all AP radiographic zones from 1-month to latest follow-up compared to the tobacco user group; however, only AP Zone 1 reached statistical significance indicated by the bold value ($P = .022$). AP, anteroposterior.

## Conclusions

Tobacco nonusers demonstrated greater resolution of radiolucent lines in all radiographic zones of the cementless tibial component on AP radiographs, with a significant reduction in AP zone 1, at a mean of 2.5 years. Similarly, tobacco nonusers demonstrated greater resolution of radiolucent lines in most lateral radiographic zones. These study results suggest promising early radiographic osseointegration of these modern cementless tibial component designs regardless of tobacco usage. However, tobacco usage may still be a significant risk factor for failure of osseointegration in the mid to long term follow-up period. Additional studies with long-term follow-up are crucial to fully discern the relationship of tobacco usage and biologic fixation in cementless TKA.

## Conflicts of interest

Andrew Carlone is a paid presentor for Enovis. Michael Meneghini is a Board member for IOEN, The Knee Society, AAHKS, The Hip Society, and MAOA; is a part of Medical/Orthopaedic publications editorial/governing board of The Journal of Arthroplasty and Orthopedics Today; received research support from Enovis; discloses stock options at EMOVI and PeekMed; is a paid consultant for Enovis, OsteoRemedies, Kinamed, and KCI/3M; and has received royalties from Enovis, OsteoRemedies, Kinamed, and Innomed. Kevin Sonn is paid presentator for Enovis. The other authors declare no potential conflicts of interests.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2022.101082.

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