ORTHOPAEDIC SURGERY

The effects of tourniquet on cement penetration in total knee arthroplasty

Stephen G. Zak[1] · Alex Tang[1] · Robert Pivec[2] · Morteza Meftah[1] · Matthew S. Austin[2] · Erik Schnaser[3] ·
Ran Schwarzkopf[1]

Abstract

Purpose Aseptic loosening is a common cause of implant failure following total knee arthroplasty (TKA). Cement penetration depth is a known factor that determines an implant's "strength" and plays an important role in preventing aseptic loosening. Tourniquet use is thought to facilitate cement penetration, but its use has mixed reviews. The aim of this study was to compare cement penetration depth between tourniquet and tourniquet-less TKA patients.

Methods A multicenter retrospective review was conducted. Patients were randomized preoperatively to undergo TKA with or without the use of an intraoperative tourniquet. The variables collected were cement penetration measurements in millimeters (mm) within a 1-month post-operative period, length of stay (LOS), and baseline demographics. Measurements were taken by two independent raters and made in accordance to the zones described by the Knee Society Radiographic Evaluation System and methodology used in previous studies.

Results A total of 357 TKA patients were studied. No demographic differences were found between tourniquet ($n = 189$) and tourniquet-less ($n = 168$) cohorts. However, the tourniquet cohort had statistically, but not clinically, greater average cement penetration depth [2.4 ± 0.6 mm (range 1.2–4.1 mm) vs. 2.2 ± 0.5 mm (range 1.0–4.3 mm, $p = 0.01$)]. Moreover, the tourniquet cohort had a significantly greater proportion of patients with an average penetration depth within the accepted zone of 2 mm or greater (78.9% vs. 67.3%, $p = 0.02$).

Conclusion Tourniquet use does not affect average penetration depth but increases the likelihood of achieving optimal cement penetration depth. Further study is warranted to determine whether this increased likelihood of optimal cement penetration depth yields lower revision rates.

Keywords Total knee arthroplasty · Tourniquet · Cement penetration

Introduction

Total knee arthroplasty (TKA) remains the gold standard for treating end-stage osteoarthritis of the knee [1–3]. However, it is reported that 2–5.7% of TKA require a revision within five years of the operation [4–6]. While common causes for revision include instability, malalignment and periprosthetic infections, aseptic loosening remains one of the most common causes of implant failure leading to revision, contributing up to 28.7% of all revision cases [7–11]. With a projected growth of TKA procedures by 673% in the United States by 2030, aseptic loosening will potentially burden patients and healthcare systems both physically and economically due to the increase in revision rates [12]. Aseptic loosening poses serious consequences to both patients and the healthcare system and has been shown to be in part due to thin cement mantles [13, 14].

Cement penetration depth is one of the principal factors that determines an implant's fixation strength in addition to other elements such as implant design and patient bone quality. Thinner cement mantles have been associated with

✉ Ran Schwarzkopf
ran.schwarzkopf@nyulangone.org

1 Division of Adult Reconstruction, NYU Langone Orthopedic Hospital, Hospital for Joint Diseases, NYU Langone Health, 301 East 17th Street, New York, NY 10003, USA

2 Department of Orthopaedic Surgery, The Rothman Institute, Thomas Jefferson University, Philadelphia, PA, USA

3 Desert Orthopedic Center, Eisenhower Medical Center, Rancho Mirage, CA, USA

early aseptic loosening, particularly when there is less than 2 mm (mm) of cement penetration depth [13, 14]. To strengthen the bone-implant interface studies have shown that the optimal penetration in TKA should be between 3 and 5 mm [15–17]. While it is accepted that a minimum of 2–3 mm of cement penetration is required to reach the first transverse trabeculae, most studies find that cement penetration enters this zone on average, but fails to reach the optimal 3 mm depth [1, 17–20]. While surgeons currently employ a variety of methods to assist in the cementation process, a standard technique that enables surgeons to reach optimal cement penetration depth or close to this zone is still required.

Intraoperative tourniquet use in TKA has become a common practice due to its proposed benefits such as improved visualization of the surgical field, decreased intraoperative blood loss, and its ability to facilitate the cementation process [21, 22]. Tourniquet use is thought to facilitate cementation for several reasons including its ability to create a clearer surgical field and minimize contamination of implant components by fat or blood, which can hinder the penetration process [23]. Additionally, it has been shown that bleeding and high blood flow rates can hinder the depth of cement penetration [24, 25]. However, many of the proposed advantages of tourniquet use such as decreased blood loss and greater cement penetration have been contradicted by recent studies [11, 26]. Postoperative outcomes of patients who underwent a TKA utilizing an intraoperative tourniquet have been shown to be lower in some studies in comparison to tourniquet-less operations as tourniquet patients may experience slower recovery and decreased quadriceps strength [27, 28]. Additionally, prolonged intraoperative tourniquet use has been associated with severe complications including nerve injury, postoperative wound hypoxia, stiffness and swelling of the joints, as well as increased risk of postoperative pain [29–32]. While there are several major proposed benefits to intraoperative tourniquet use, the mixed results in the literature and the potential for serious complications has left the use of tourniquet in TKA to the discretion of orthopedic surgeon preference.

As the demand for TKA rises, the need to standardize techniques to facilitate optimal cement penetration to ultimately reduce revision rates in aseptic loosening becomes increasingly important. Therefore, we conducted a retrospective review of two different studies' cohorts comparing the cement penetration depth between patients who underwent tourniquet and tourniquet-less TKA. In this study, we sought to determine if there was a difference in cement penetration between tourniquet and tourniquet-less TKA patients. We hypothesized that patients undergoing TKA with the use of an intraoperative tourniquet would have greater cement penetration than patients undergoing tourniquet-less TKA.

Methods

A retrospective review of a cohort of patients in two previously performed randomized controlled trials (RCT) performed contemporaneously at three, academic medical centers who underwent a TKA from November 2018 to February 2020 was performed [33, 34]. Both RCTs as well as the current study received Institution Review Board (IRB) approval at their respective institutions. Both RCTs were primarily designed to study the effect of tourniquet use on post-operative pain. Patients were eligible for the present study if they were greater than or equal to 18-years-old, undergoing elective primary TKA, and had tibial anteroposterior (AP) and lateral X-ray images within one month post-operatively available. The variables that were collected in the study were cement penetration measurements (in mm) by radiographic zone, length of stay, (LOS), and baseline patient demographics, such as age, body mass index (BMI), gender, race, smoking status, and American Society of Anesthesiologists (ASA) score. Implants used within these two RCTs included Smith and Nephew Journey II (Smith & Nephew, Memphis, TN) and Legion (Smith & Nephew, Memphis, TN) as well as Zimmer Persona (Zimmer-Biomet, Warsaw, IN). Each site within this study utilized a different cementing protocol. The majority of cases utilized high viscosity cement (64%); low (26.7%) and medium viscosity (9.3%) cements were used in the remaining cases. The method of cement application also differed between sites with some applying cement with a gun while the other used a finger packing and spreading technique, technique was constant throughout the study for each surgeon. All surgeons applied cement to both the implant, tibial bone surface and canal metaphysis. Average cement penetration between the two RCTs was statistically similar. The primary outcome of the study was cement penetration between tourniquet and tourniquet-less TKA patients.

Participants

A total of 357 TKA patients were identified throughout the study period. Patients were separated into two cohorts based on tourniquet use: 189 TKA cases were identified as having used a tourniquet and 168 TKA cases did not. Within the tourniquet group, the average age was 66.01 ± 8.3 years, average BMI was 30.5 ± 5.4 kg/m^2, and average ASA class was 2.3 ± 0.5. Moreover, the majority of patients in the tourniquet group were female (65% vs 35% male). Non-smokers comprised of 65% of the tourniquet group, followed by former smokers (25%), and current smokers (10%). On average, the patients in the

tourniquet-less group were 66.02 ± 9.7-years-old, had a BMI of 31.2 ± 5.1 kg/m^2, and ASA class of 2.3 ± 0.5. Like the tourniquet group, the majority of patients in the tourniquet-less group were non-smokers (74% vs 17% former smokers vs 9% current smokers). The two cohorts in this study were found to be demographically similar in regard to age ($p = 1.0$), BMI ($p = 0.2$), sex ($p = 0.3$), race ($p = 0.6$). smoking status ($p = 0.4$) as well as ASA class ($p = 1.0$) and LOS (Table 1).

Radiographic cement penetration measurements

Radiographs in this study were accessed using participating institutions' digital radiograph repositories, picture archiving and communication system (PACS). Measurements were made on radiographs found closest to one-month post-operatively and were preferentially taken on images with implant views collinear to the x-ray beam. Radiographs were measured using a digital ruler calibrated to the thickness of each tibial baseplate. Using this calibrated ruler, each zone was divided into the appropriate number of sections.

Measurements were made in accordance to the zones described by the Knee Society Radiographic Evaluation

Table 1 Basic Demographic Data of the two cohorts: tourniquet and tourniquet-less TKA

Demographics			
	Tourniquet-less ($n = 168$)	Tourniquet ($n = 189$)	P-value
Age	66.02 ± 9.7	66.01 ± 8.3	1.0
Sex			0.3
Female	110	113	
Male	58	76	
BMI	31.2 ± 5.1	30.5 ± 5.4	0.2
Race			0.6
White	103	102	
African American (Black)	23	40	
Other race	42	47	
Smoking status			0.4
Never	124	12	
Former	28	48	
Current	16	19	
ASA			1.0
1	7	19	
2	104	116	
3	57	64	
4	0	0	
LOS	1.8 ± 1.2	1.6 ± 1.07	0.2

P-values are derived from two-tailed t-test for numerical values or $\chi 2$ tests for categorical values
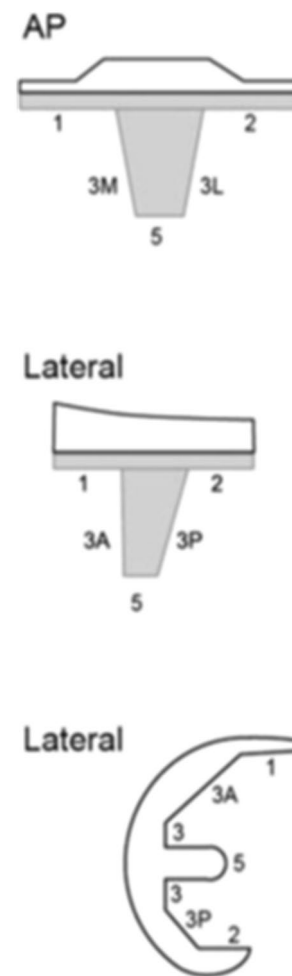

Fig. 1 Radiographic zones defined by the Knee Society Radiographic Evaluation System (11)

System and used in previous studies of the topic (Figs. 1, 2) [11, 35]. Tibial AP zone 1 signifies the medial inferior surface while zone 2 denotes the lateral inferior surfaces of the tibial baseplate. On the lateral tibial view, zone 1 represents the anterior surface while zone 2 designates the distal surface. Lateral femoral zones include 3A, 3, and 3P which represent the anterior, distal and posterior proximal surfaces respectively. In accordance with other published literature on the topic, zones 1 and 2 of the AP and lateral tibia views were split into thirds and depth measurements were made at the one-third and two-third marks [11]. For femoral measurements, zone 3A was split into thirds and again measured at the one-third and two-third marks. Cement penetration was measured at the one-half mark for zones 3 and 3P. Measurements were made from the most distal part of the implant to the most distal part of the cement mantle [11]. For zones in which more than one measurement were made, the average was taken to determine a complete penetration depth for that zone.
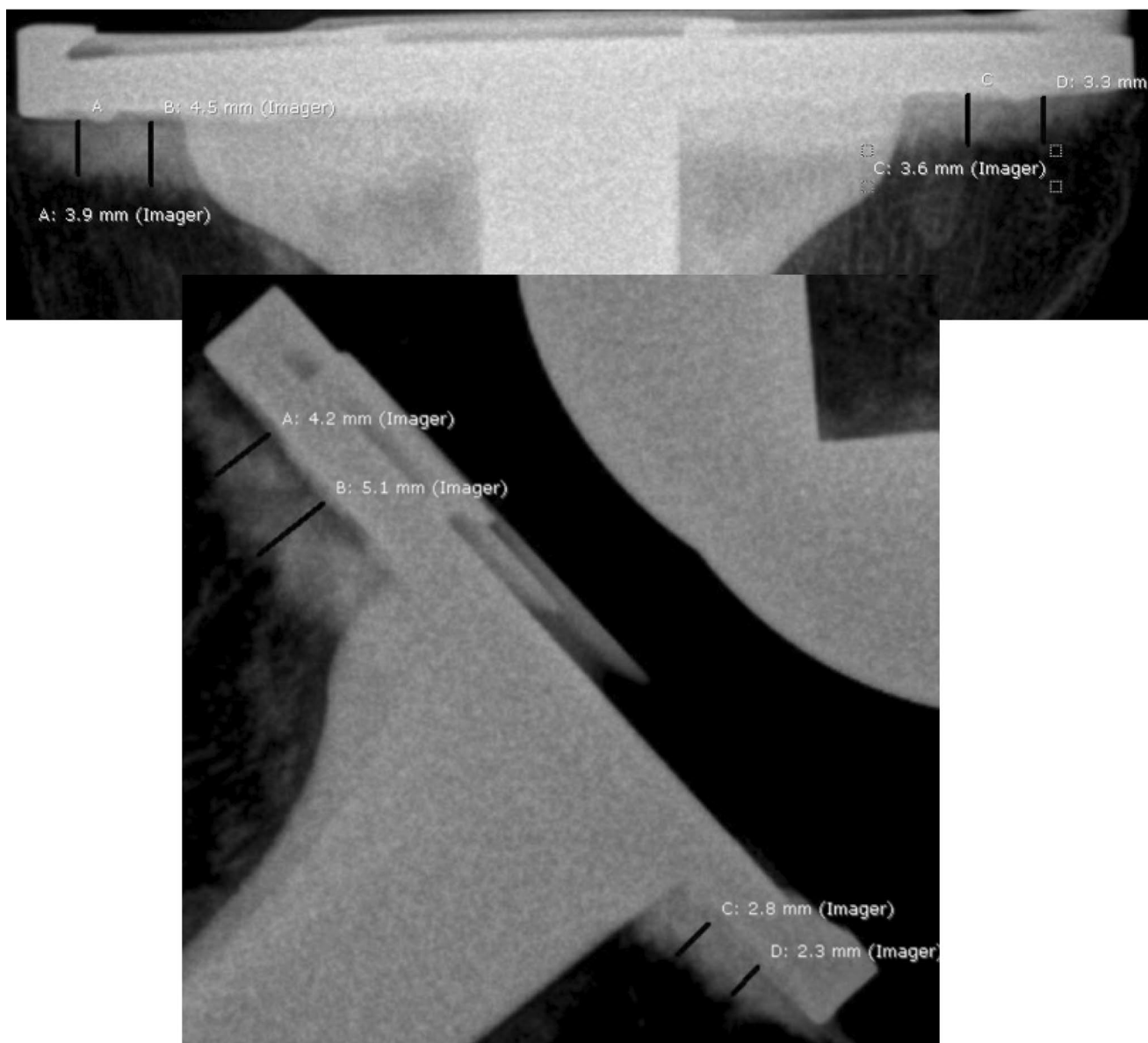
Fig. 2 Example of Radiographic Measurements from an AP view (top) and Lateral view (bottom)

All measurements were taken independently by two trained evaluators. If differences greater than 1.0 mm were found, each rater independently repeated the measurements until agreement within 1.0 mm was reached as described by previous studies on the topic [11]. Depth measurements from both raters were averaged to determine the average depth for each zone.

Statistical analysis

Descriptive statistics were recorded as means $\pm$ standard deviation for continuous variables or counts (%) for categorical variables. Independent sample, two-tailed t-tests were used to test for differences between continuous data (e.g.

cement penetration, length of stay, patient age and BMI) and χ^2 tests were used for categorical data (e.g. gender, race, smoking status, ASA). All statistical analyses were performed using SPSS v25 (IBM Corporation, Armonk, New York). A p-value of less than 0.05 was considered to be statistically significant.

Results

Our results showed that the average cement penetration depth was significantly greater in the tourniquet cohort than the tourniquet-less cohort [2.4 $\pm$ 0.6 mm (range 1.2–4.1 mm) vs 2.3 $\pm$ 0.5 mm (range 1.0–4.3 mm), $p = 0.01$] (Table 2 and

Table 2 Cement Penetration Depths separated into the different zones described by the Knee Society Radiographic Evaluation

Cement Penetration (mm) by Radiographic Zone			
	Tourni-quet-less ($n = 168$)	Tourniquet ($n = 189$)	P-value
Overall			
Average across 7 zones	2.3 ± 0.5	2.4 ± 0.6	0.01
AP Tibia			
Zone 1	2.2 ± 0.9	2.5 ± 0.9	0.007
Zone 2	2.1 ± 0.8	2.3 ± 1.0	0.08
Lateral Tibia			
Zone 1	2.6 ± 0.9	2.7 ± 1.2	0.3
Zone 2	2.5 ± 0.6	2.9 ± 1.06	0.1
Lateral Femur			
Zone 3A	2.2 ± 0.8	2.2 ± 0.8	0.9
Zone 3	2.06 ± 0.6	2.3 ± 0.8	0.06
Zone 3P	1.5 ± 0.9	1.6 ± 0.9	0.4

Fig. 3). While the ranges for both cohorts were similar, the tourniquet cohort had a greater percentage of patients who had penetration within the accepted zone of 2 mm or greater penetration depth (78.9% v. 67.3% $p = 0.02$) as well as a greater percentage of those who reached the optimal 3 mm or higher depth (16.2% vs 8.7%; $p = 0.05$). However, the tourniquet and tourniquet-less cohorts were found to have a similar number of zones with less than 2 mm of cement mantle (3.0 ± 2.0 mm vs 3.5 ± 2.1 mm, $p = 0.2$).

In regard to the specific parameters that made up the average cement penetration, tourniquet patients had a greater cement penetration depth in AP Tibia Zone 1 than tourniquet-less patients (2.5 ± 0.9 mm vs 2.2 ± 0.9 mm, $p = 0.007$). Lateral Femoral Zone 3 neared significance again with the tourniquet cohort trending towards slightly greater penetration depth (2.3 ± 0.8 mm vs 2.06 ± 0.6 mm; $p = 0.06$). No other significant differences were found in any other zones between the two groups.

Additional sub-analysis was also conducted on the tourniquet-cohort in regard to how long a tourniquet was used. Tourniquet use during cementation was shown to have no statistical effect on average cement penetration depth compared to those that used a tourniquet for the entirety of the case (2.3 ± 0.5 vs 2.5 ± 0.8; $p = 0.3$). Tourniquet use for the entirety of the case yielded a similar number of patients reaching a penetration depth of 2 mm (75.9% vs 87.5%; $p = 0.9$) and 3 mm (11.5% vs 23.2%; $p = 0.03$) in comparison to the group that only had a tourniquet utilized for cementation. In addition, neither the group using a tourniquet for the entirety of the case nor the group using a tourniquet only for cementation had a statistically different average penetration depth in comparison to the completely tourniquet-free cohort ($p = 0.9$; $p = 0.1$).

Discussion

Previous studies have shown that intraoperative tourniquet use has multiple surgical benefits such as improved visualization of the surgical field, deceased blood loss, decreased operative time, and improved cementation [21, 22]. In our study, the use of an intra-operative tourniquet was associated with a significantly greater cement penetration average depth

Fig. 3 Cement Penetration Depths separated into the different zones described by the Knee Society Radiographic Evaluation
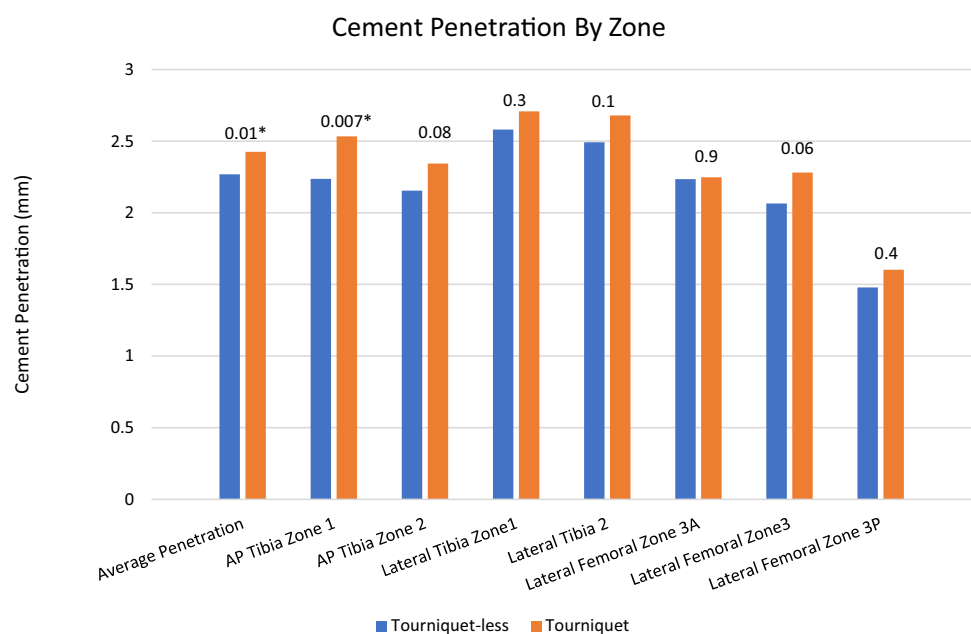
than tourniquet-less TKA (2.4 mm vs 2.3 mm, $p = 0.01$), particularly in tibial zone 1 ($p = 0.007$) and possibly lateral femoral zone 3 ($p = 0.06$). Much of the literature that supports tourniquet use in regards to cement penetration hypothesizes that the decreased blood flow prevents the interference of the bone-cement interface at the time of cementation [25, 36]. Nevertheless, many surgeons opt for tourniquet-less TKA due to negative reports which have shown that intraoperative tourniquet use leads to greater postoperative pain and slower recovery times. However, if tourniquet use does increase cement penetration, it has the potential to increase the longevity of an implant and potentially decrease revision rates related to aseptic loosening due to the impact of cementation.

While our results showed that average cement penetration was statistically different between the two cohorts, the clinical significance of a difference of 0.15 mm is minimal. Both of our study's cohorts experienced average penetration within the accepted penetration zone of 2–3 mm, but fell short of the optimal 3–5 mm zone [15–17]. Our results reflect many of the cement penetration depths recorded in the literature and do not stand as outliers [1, 11, 20]. Ozkunt et al. found similar differences in depth between tourniquet and tourniquet-less operations but their results were not significant, most likely due to the smaller sample size of 69 cases [1]. While our results show that tourniquet use is associated with a statistical increase in penetration depth, there appears to be no major benefit as both techniques yielded penetration depths that represent the average values found in the literature.

It is commonly accepted that a cement penetration depth of at least 2 mm or greater is required for long-term fixation [15–17, 37]. While the ranges for average penetration depth in both cohorts were similar, the tourniquet cohort had a greater percentage of patients who had penetration within the accepted zone of 2 mm or greater penetration depth as well as a greater percentage of those who reached the optimal 3 mm or higher depth. These finding suggests that the use of an intraoperative tourniquet in TKA could have real clinical significance. However, both groups had a similar number of radiographic zones that had smaller than 2 mm cement mantle. The current literature shows that the greater the number of radiographic zones with less than 2 mm of penetration depth, the greater the likelihood of aseptic loosening and malalignment [14]. Studies such as those by Banwart et al. have shown that the removing excess fluids and fats before cementation enhances penetration [23]. The use of an intraoperative tourniquet allows for a clearer surgical site which in turn allows for less interference of the bone-cement interface [32]. In addition, tourniquet also helps to minimize blood circulation around the surgical region which has also been shown to negatively affect penetration [24, 25]. Our results show that while the use of a tourniquet increased

the chance of reaching an overall adequate and optimal mantle thickness, some zones achieved high penetration while other zones failed to reach an adequate penetration depth. It follows that intraoperative tourniquet does not harm average cement penetration depth and perhaps increases penetration in some zones.

In addition to examining the benefits of tourniquet in comparison to tourniquet-less TKA on cement penetration, we sought to determine if the length of time the tourniquet was used for played any role in the cementation process. The surgeons we reviewed in this study either utilized the tourniquet for the entirety of their cases and deflated their tourniquets after the cement has completely cured or only used the tourniquet for cementation. While our findings were underpowered, we showed that the length of tourniquet usage had no effect on average cement penetration depth, and tourniquet use for the entire case led only to a slight increase in the percentage of patients reaching optimal cement penetration depth. While longer tourniquet use has been shown to lead to less blood loss and faster surgical times, our results match those of other studies showing that cement penetration depth does not differ between groups that utilized a tourniquet for the entire case versus just during the cementation period [38, 39]. These findings suggest that, in regards to cement mantle depth and implant fixation, tourniquet use is most important during the cementation process. The lack of a significant difference between tourniquet and tourniquet-less groups in regards to cement penetration depth echoes other recent studies such as those by Jawhar et al. and Ozkunt et al. [1, 40]. However, since tourniquet use for the full case or just for cementing appears to decreased variability in cement penetration equally, shorter usage may be beneficial. Previous studies report that shorter tourniquet use results in lower pain scores in comparison to long-term use [1, 40]. While the wariness of surgeons about tourniquet's potential negative patient outcomes concerning pain and slower recovery times may be valid, the results of study showed that it may have a positive effect on cement penetration. However, further study is required to determine the impact this greater depth has on clinical outcomes and implant life-span. It follows that intra-operative tourniquet use should be left to surgeon preference and discretion.

Our study has several limitations. Penetration measurements are somewhat subjective with definitive distal-ends of the cement mantle often being unclear on plain radiographs. To minimize this ambiguity, two trained raters made measurements independently using a similar methodology that Gapinski et al. utilized [11]. Measurements were averaged together and deemed acceptable as long as they were within 1 mm of each other. Additionally, our study did not take into consideration bone density which could have an impact on cement penetration. However, with similar demographics between cohorts, factors such as age that influence

bone density were minimized. In addition, different cement viscosities were used in this study which may have affected penetration depth. However, recent clinical studies have showed that when the same implants and cementing technique are used, high and low viscosity cements have similar penetration depth [41]. Despite these limitations, the results of our study suggest that while tourniquet use does not clinically significantly increase average cement penetration, it decreases variability, allowing for a greater rate of penetration into the accepted zone of permeation for proper fixation.

Conclusion

Our study demonstrated that while tourniquet use does not clinically increase average penetration depth, it increased the likelihood of achieving adequate and optimal cement penetration depth. Further studies are warranted to determine whether optimal penetration depth in certain zones with tourniquet use yields lower future revision rates.

Author contributions SGZ: writing original draft, writing review and editing. AT: writing review and editing. RP: formal analysis and investigation. MM: conceptualization, writing-review and editing, participating surgeon. MSA: conceptualization, writing-review and editing, participating surgeon. ES: conceptualization, writing- review and editing, participating surgeon. RS: supervision, writing- review and editing, participating surgeon.

Availability of data and materials The data used in this study is from the authors' institution and is available from the corresponding author, RS, upon reasonable request.

Declarations

Conflict of interests Mr. Stephen G. Zak has no conflicts of interest. Mr. Alex Tang has no conflicts of interest. Dr. Robert Pivec has no conflicts of interest. Dr. Morteza Meftah received royalties from Innomed and owns stock in CAIRA surgical. Morteza Meftah is also a paid consultant for Intellijoint. Dr. Matthew S. Austin own stock in and is a paid speaker for Corin USA. Dr. Erik Schnaser is a paid speaker for Orthoalign, Smith & Nephew and Stryker; is a paid consultant for Smith & Nephew and Zimmer. Erik Schnaser also received research support from Lima and Smith & Nephew. Dr. Ran Schwarzkopf receives royalties from Smith & Nephew; is a paid consultant for Inteljoint and Smith & Nephew; and owns stocks in Gauss surgical and Intelijoint. Ran Schwarzkopf also receives research support from Smith & Nephew.

Ethical approval This study has obtained all required IRB and ethical approval at our institution.

Informed consent This study is a retrospective review in which patients were subject to their normal standard of care. No individual data is included within this study.

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