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Effect of high-pressure pulsatile lavage versus manual rinsing on bone cement penetration in total knee arthroplasty: a randomized clinical trial

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Abstract

Background Bone irrigation is a crucial step in cemented total knee arthroplasty procedures to promote maximal cement penetration and interdigitation into the cancellous bone. However, it is not clear which type of bone irrigation achieves the best results. This study aimed to compare the efficacy of high-pressure pulsatile lavage versus manual rinsing in promoting bone cement penetration during total knee arthroplasty.

Methods We conducted a single-center, prospective, randomized, controlled clinical trial in 100 patients undergoing primary total knee arthroplasty during 1 year. All patients were randomly allocated to either the pulsed lavage group or the non-pulsed lavage group. We assessed total cement penetration depth across all zones radiologically using anteroposterior and lateral radiographic views in postoperative X-rays taken on the first day after surgery and segmenting them into ten zones according to the Knee Society Scoring System (KSSS).

Results The patient cohort included 100 individuals with an average age of 75 years (standard deviation [SD] 5.7); 73% were female. The mean total bone cement penetration values in both anteroposterior (AP) and lateral views were 10.77 mm (SD 5.95) and 4.85 mm (SD 3.33) for manual lavage, and 11.34 mm (SD 6.26) and 5.23 mm (SD 3.50) for pressurized lavage. We observed no significant differences between the two groups after adjusting for multiple variables.

Conclusions High-pressure pulsatile lavage showed no significant differences in enhancing bone cement penetration compared with manual lavage as measured by the KSSS total knee arthroplasty bone cementation scale in X-rays taken on the first postoperative day.

Level of Evidence Level I—Therapeutic randomized controlled trial.

Trial registration Clinicaltrials.gov Register-NCT06032507

Keywords Total knee arthroplasty, Total knee arthroplasty cementation, Bone cement penetration, High pressure pulsatile lavage, Pulsatile lavage

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Background

Cemented total knee arthroplasty (TKA) is the gold standard for surgical treatment of knee osteoarthritis and consistently delivers excellent clinical and functional results, as documented in numerous studies [1, 2]. Survival rates of 90% over 15 years can be achieved [3]. However, a significant cause for revision is the aseptic loosening of the tibial component. [4] This loosening can occur at the bone-cement interface or at the cement-implant interface, highlighting the pivotal role that the cementing technique plays in securing initial fixation of TKA components by reducing micromotion and thereby enhancing implant stability and longevity [5, 6].

Enhancing the bone-cement interface through optimal cement penetration and interdigitation into the cancellous bone is a critical objective of bone irrigation in the cemented TKA surgical technique [7]. Several irrigation techniques, such as manual rinsing, brush, and high-pressure pulsed lavage have been performed before cementing in cadaveric studies [8–15]. However, in vivo studies analyzing the effect of the various irrigation techniques on cement penetration remain limited. Current comparative studies evaluating cement penetration have been conducted exclusively on cadaveric specimens, demonstrating greater cement penetration with the use of pulsatile lavage. However, to our knowledge, there are no comparative in vivo studies in the literature directly assessing differences in cement penetration between pulsatile and manual lavage techniques. This highlights a significant gap in the current evidence base regarding clinical outcomes associated with different lavage methods in live patients [16–18].

The purpose of the present study was to compare the effectiveness of high-pressure pulsatile lavage and manual rinsing in promoting penetration of bone cement during TKA procedures. We hypothesized that high-pressure pulsatile lavage could increase the intrusion of the cement into cancellous bone.

Methods

Study design

A single-center, prospective, therapeutic, randomized clinical trial was carried out from September 2021 to September 2022. Patients undergoing primary TKA were randomly assigned to either a high-pressure pulsatile lavage group or a manual rinsing group prior to TKA cementation. The flow chart diagram is shown in Fig. 1. The study was approved by the Ethics Committee and Research Institute at our institution. The study protocol was registered at ClinicalTrials.gov.

Study population

All patients were eligible to participate if they had clinical symptoms of knee osteoarthritis but had not responded to conservative treatment measures with the established criteria and recommendations of the knee surgeon's team [19]. Patients were excluded if they had metal allergies, active or latent knee sepsis, dysfunction of the extensor mechanism, morbid obesity, severe peripheral vascular disease, or major psychiatric or neurological disorders. All participants provided informed consent to participate in the study and consent for publication of the results.

Randomization

Patients who met the inclusion criteria were consecutively included in the study on the basis of the inclusion criteria and upon signing the informed consent form. Once deemed eligible, they were randomized to receive either high-pressure pulsatile lavage (high-pressure group) or manual rinsing (manual group) prior to TKA cementation. The randomization model was devised in blocks of ten using a 1:1 ratio (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp). Allocation was facilitated through sequentially numbered, sealed, opaque envelopes that were opened immediately before the bone cementation process.

Baseline data

Patient characteristics, obtained from patients' clinical charts, were age (years), weight (kg), body mass index (BMI; range), smoking habit, previous disease (high blood pressure, diabetes mellitus, coronary heart disease, peripheral arteriopathy, rheumatoid arthritis, or chondrocalcinosis), and the radiographic grade of osteoarthritis assessed by our knee orthopedics team following the Kellgren–Lawrence classification [20].

Intervention—Surgical technique

All TKA were implanted according to a standard protocol. Cemented TKA was performed by four senior knee surgeons following the standard medial parapatellar approach with tourniquet. A cemented Triathlon® prosthesis was implanted (Stryker, Kalamazoo, Michigan, USA). For the cementation, 60 g of Simplex (Stryker, Kalamazoo, Michigan, USA) bone cement without antibiotic was applied.

High-pressure pulsatile lavage versus manual rinsing

Bone irrigation was performed following assignment by means of sealed randomization envelopes opened during surgery immediately before the cementation

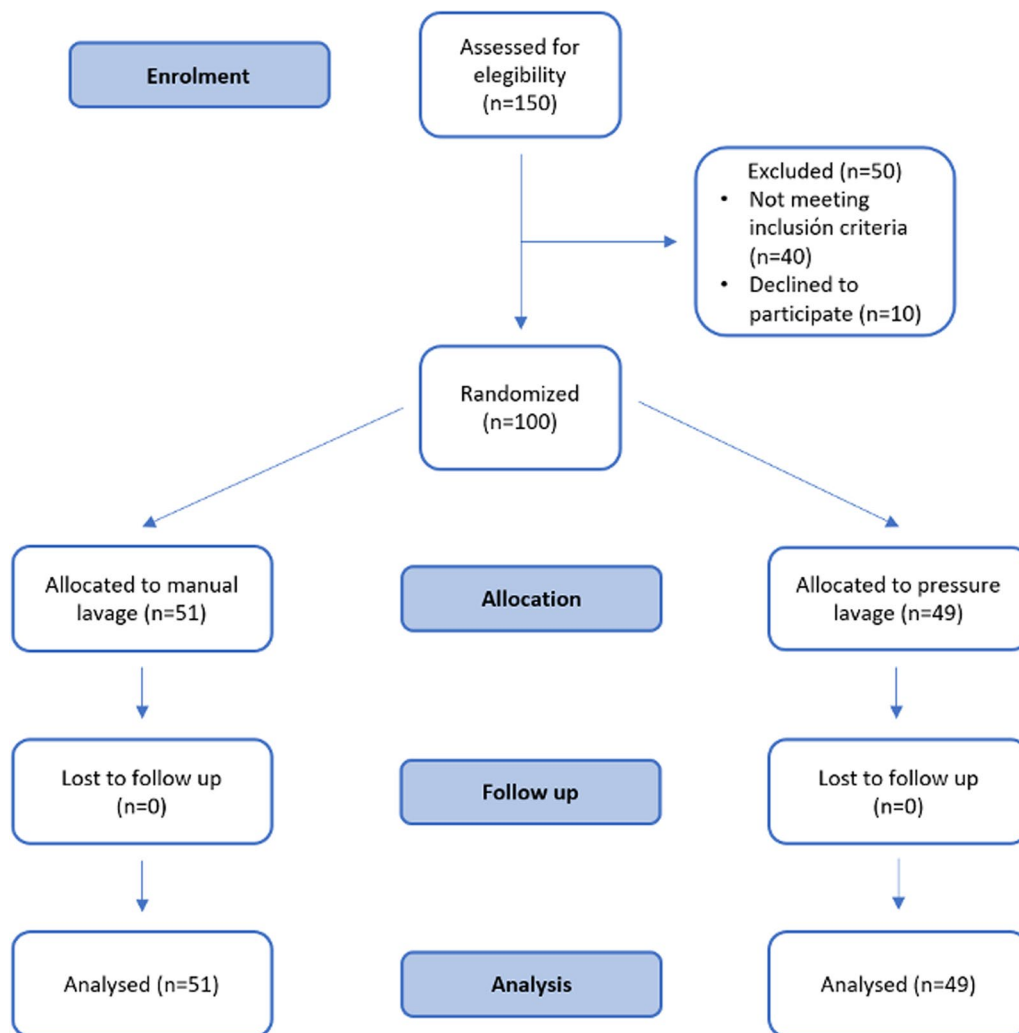


Fig. 1 Flow diagram showing the study design

process. Both manual rinsing and high-pressure pulsatile lavage were performed for both approaches using 3 L of saline solution for 5 min. Manual rinsing was administered using a bottle with irrigation solution NaCl 0.9% sterile and endotoxin-free (B Braun, Melsungen, Hessen, Germany) (Fig. 2). High-pressure pulsatile lavage was administered using Cleanest™ (Sungro Europe B.V, Netherlands) (Fig. 3). The cement was manually applied and digitally pressurized on the tibia bone surface before implanting the tibial tray.

Outcome: bone cement penetration

Bone cement penetration in TKA was evaluated using the standard Knee Society Scoring System (KSSS), recognized as an accessible, reliable, and reproducible method. [19]. Evaluations were conducted by three distinct observers: a senior orthopedic surgeon, a junior

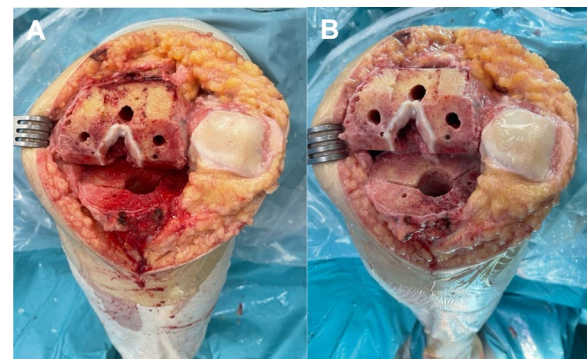


Fig. 2 Surgical image of the knee immediately before (A) and after (B) manual-rinsing lavage

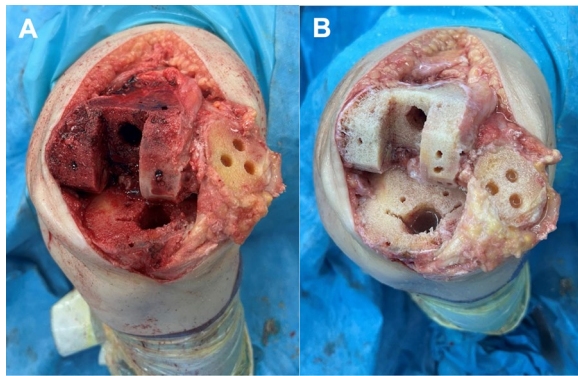


Fig. 3 Surgical image of the knee immediately before (A) and after (B) high-pressure pulsatile lavage

orthopedic surgeon, and a senior resident. None of them were involved in the patients' treatment. All radiographs were anonymized and coded to remove patient identifiers and surgical details, and contained no information on the lavage method used. Standardized postoperative digital anteroposterior (AP) and lateral radiographs were collected and a standard magnification, followed by obliquity control to ensure the tibial plateau height was visible on both the lateral and medial aspects in the AP view, and on the anterior and posterior aspects in the lateral view.

Radiographic assessment involved delineating a perpendicular line from the lower tibial plateau to the deepest accessible bone-to-cement transition zone within each of the ten KSSS zones (seven in the AP and three in the lateral view). [21–25]. All observations were performed using the Impax BI tool © (Version 11.1.1), by AGFA Healthcare (Fig. 4).

The cumulative cement penetration in the seven AP zones and three lateral zones was expressed as the average cement penetration for each patient.

Data analyses

Sample size was calculated on the basis of the primary outcome, that is, the sum of cement penetration measurements in ten KSSS zones. This measurement was reported in previous literature and it was assumed that the variation would be approximately 11 mm (SD), with a minimum difference to assess between groups of 6.5 mm (average thickness of 0.65 in the ten zones) [21]. We estimated that losses would not exceed 10%. The value for a type I error was specified at 5% ($\alpha=0.05$, two-sided). The value for a type II error was specified at 0.2 with a minimum power of 80%. The number of patients needed to be included in this clinical trial in a perfectly balanced design was calculated as 100, randomized between the 2 groups in a ratio of 1:1 (GranMo package, V 7.12, IMIM, Barcelona, Spain). An exploratory two-sided noninferiority analysis with a 90% confidence interval was performed

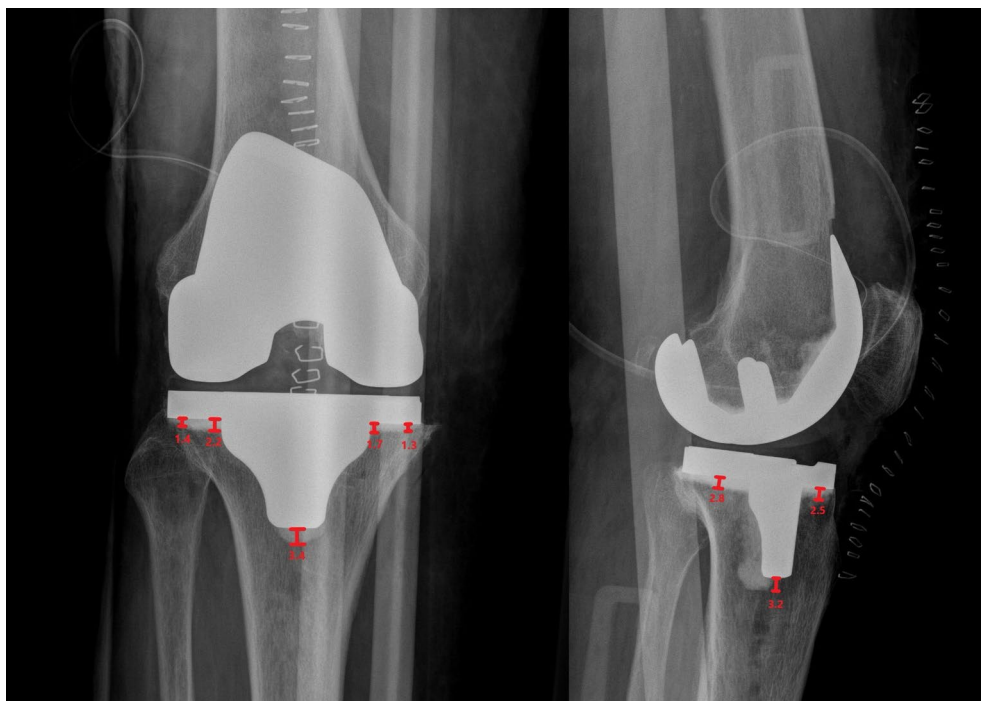


Fig. 4 Radiographic measurement of cement penetration in both AP and lateral views in total knee arthroplasty

for the cumulative cement penetration measured on postoperative AP and lateral radiographs. The noninferiority margin was set at 2 mm on the basis of the cumulative cement penetration scale reported by Sasaki et al. [26]

For the statistical analysis between the two groups we compared the cumulative scores of bone cement penetration. We analyzed categorical variables, presented as number with percentage, using the χ^2 test or Fisher's exact test. Continuous variables, presented as mean (standard deviation, SD) or median (interquartile range, IC), were analyzed using the Student's *t* test and Mann–Whitney *U* test, depending, respectively, on whether the distribution was normal. Secondary sensitivity analysis was performed excluding the metaphyseal zones that may be influenced by bone density and limited accessibility to pulsatile lavage (zones 5, 6, and 7 in the anteroposterior view and zone 3 in the lateral view) [25]. All results are reported with 95% confidence intervals (CI). A *p*-value < 0.05 was considered statistically significant. Statistical analysis was performed using the IBM-SPSS® package V26.

Results

Population characteristics

The study included 100 patients. Their mean age was 75.25 years (SD 5.78) and 73% were women. All participants were enrolled in the study and underwent TKA between September 2021 and September 2022 and all completed follow-up until postoperative X-ray control. No statistical differences were found between groups for any other patient characteristics. (Table 1).

Bone cement penetration

The average cumulative bone cement penetration on the anteroposterior view was 11.8 mm (SD 5.7) for manual lavage and 12.0 mm (SD 5.7) for pressure lavage (n.s.) (Table 2, Fig. 5). On the lateral view, it was 10.2 mm (SD 5.5) for manual lavage and 11.4 mm (SD 5.2) for pressure lavage (Table 2, Fig. 6). These differences were not statistically significant for cumulative cement penetration in the KSSS cementation zones, either in the AP view (*p*=0.644) or in the lateral view (*p*=0.582) (Table 2). Exploratory noninferiority analysis showed that manual lavage was noninferior to pressure lavage on both AP and lateral cumulative views (AP 0.20 mm (CI−1.69, 2.09) and lateral view 1.20 mm (CI−0.58, 2.98), *p*=0.001). *The sensitivity analysis, excluding zones 5, 6, and 7 in the anteroposterior view and zone 3 in the lateral view, showed no significant differences between groups.* The mean cumulative cement penetration in the anteroposterior view (zones 1–4) was 7.1 mm (95% CI 6.2, 8.0) for manual lavage and 6.9 mm (95% CI 5.9, 7.9) for pressure lavage (*p*=0.644), while in the lateral view (zones 1–2) it was 6.2 mm (95% CI 5.3, 7.1) and 6.8 mm (95% CI 5.9, 7.7), respectively (*p*=0.589).

Discussion

The main finding in this study was that no differences were found between high-pressure pulsatile lavage and manual-rinsing lavage regarding cement penetration into cancellous bone during TKA, as assessed through the KSSS in X-rays taken on the first postoperative day. To our knowledge, the present study is the first randomized clinical trial to analyze the relation between the use of pulsed lavage and tibial bone cement penetration in

Table 1 Patient baseline characteristics

	Total (N=100)	Manual lavage (n=51)	Pressure lavage (n=49)	<i>p</i> -Value
Women	73	37	36	1.000
Men	27	14	13	1.000
Age (years)	75.1 ± 6.5	75.3 ± 5.8	75.0 ± 7.3	0.860
Body mass index	29.7 ± 4.52	29.8 ± 4.1	29.6 ± 4.9	0.890
Weight (kg)	76.7 ± 14.05	76.9 ± 12.9	76.5 ± 15.2	0.880
Smoking	9	2	7	0.089
High blood pressure	62	33	29	0.681
Diabetes mellitus	19	11	8	0.613
Coronary heart disease	6	4	2	0.678
Peripheral arteriopathy	12	5	7	1.000
Rheumatoid arthritis	2	1	1	0.742
Chondrocalcinosis	23	13	10	0.358
Keller–Lawrence grade 3	45	24	21	0.693
Keller–Lawrence grade 4	55	27	28	

Table 2 Knee Society Scoring System for total knee arthroplasty

KSSS cementation zones	Total (N=100)	Manual lavage (n=51)	Pressure lavage (n=49)	
Anteroposterior view				
1	1.5±1.1	1.6±1.1	1.4±1.1	
2	2.2±1.4	2.0±1.2	2.3±1.7	
3	1.8±1.2	1.8±1.0	1.8±1.3	
4	1.5±1.0	1.7±1.0	1.4±0.9	
5	0.4±0.6	0.4±0.7	0.3±0.5	
6	4.0±4.5	3.7±4.3	4.4±4.6	
7	0.5±0.9	0.5±0.9	0.5±1.0	
Average cumulative cement penetration	11.9±5.7	11.8±5.7	12.0±5.7	$p=0.644$ $p=0.659^a$
Lateral view				
1	3.4±1.6	3.2±1.7	3.6±1.5	
2	3.1±1.8	3.0±1.9	3.2±1.6	
3	4.3±4.7	4.1±4.5	4.6±5.0	
Average cumulative cement penetration	10.8±5.3	10.2±5.5	11.4±5.2	$p=0.582$ $p=0.600^a$

The values are given as the average ± standard deviation

^a Multivariable model with no statistically significant differences were observed for the included covariates

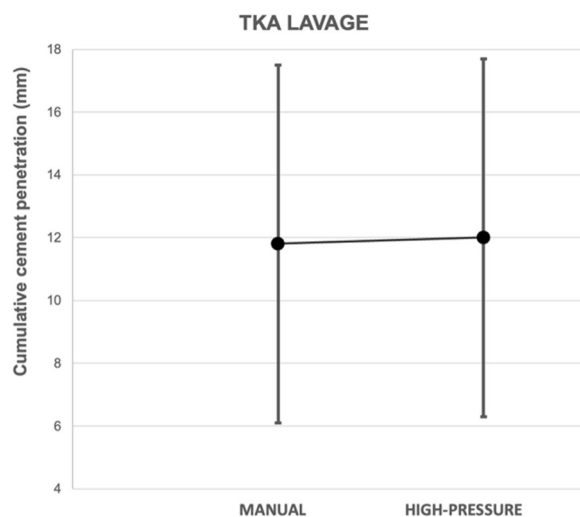


Fig. 5 Differences between manual lavage and pressure lavage regarding cumulative cement penetration for zones 1–7 in the anteroposterior view

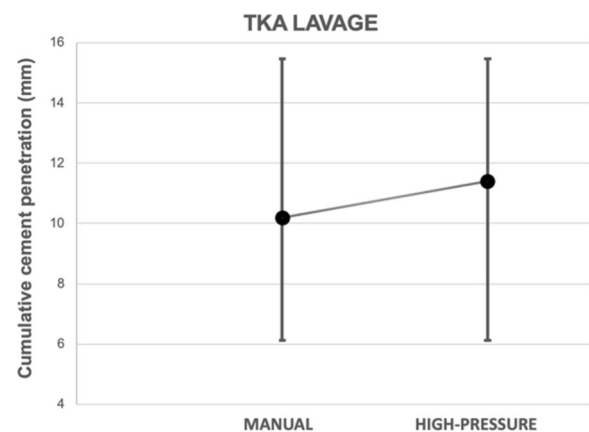


Fig. 6 Differences between manual lavage and pressure lavage regarding cumulative cement penetration for zones 1–3 in the lateral view

primary TKA. Although the irrigation technique before cementing is of great importance to avoid early failures and to achieve high survival rates on TKA, [5, 6] few studies have evaluated cement penetration after pulsed lavage or compared this with other forms of lavage. Furthermore, most studies to date have been carried out in cadaver knee specimens.

In a comparative study in ten cadaveric specimens, Boontanapibul et al. [9] found that combining

innovative pressurized carbon dioxide lavage and pulsatile normal saline irrigation before TKA implantation produced significantly deeper cement penetration into cancellous bone than pulsatile normal irrigation alone (1.90 ± 0.39 mm versus 1.21 ± 0.21 mm, $p=0.04$). They calculated cement penetration using digital vernier calipers after the proximal tibia was cut on three planes following TKA implantation; they did not, however, include a radiographic assessment. In another study, Schlegel et al. [13] reported their results from a series of six pairs of cadaveric tibiae, showing that

cement penetration was greater in the pulsed lavage group combined with finger packing of bone cement than on syringe lavage and gun cementing (1.47 mm in the pulsed lavage group and 0.4 mm in the syringe lavage group; $p=0.004$). They calculated cement penetration by computed tomography (CT) but applied a release agent to the tray undersurface prior to implantation, and evaluated CT after implant removal. Previously, Schlegel et al. [14] evaluated scans of bone cement penetration in six pairs of cadaveric specimens in TKA. They found that cement penetration was significantly higher in the pulsed lavage group than in the syringe lavage group (1.32 mm versus 0.79 mm; $p=0.031$). They calculated cement penetration by CT with a median cement penetration depth and range for the entire cemented area. The present study was performed in vivo in 100 patients. We found no differences in cement penetration between high-pressure pulsatile lavage and manual-rinsing lavage (11.8 versus 12.0 mm on anteroposterior view; $p=0.644$; and 10.2 versus 11.4 mm on lateral view; $p=0.582$). Cement penetration was calculated by postoperative X-ray according to the KSSS. Manual lavage was noninferior to pulsatile lavage for cement penetration, with values above the threshold linked to a reduced risk of radiolucent lines >2 mm. Higher cement penetration values observed in zone 6 of the anteroposterior view and zone 3 of the lateral view likely correspond to the metaphyseal region, where local variations in bone density and the limited accessibility of pulsatile lavage may influence cement distribution [25]. However, the sensitivity analysis excluding these areas yielded no significant differences between manual and pressure lavage groups, suggesting higher penetration values in these zones.

In addition to clinical considerations, practical factors related to surgical efficiency and resource utilization should also be taken into account. Manual rinsing, in contrast to pulsatile lavage, is associated with reduced economic cost, shorter procedural time, and decreased demand for operative equipment.

Regarding in vivo studies, Ritter et al. [18] divided 221 patients treated with TKA into three groups on the basis of the preparation of the surface of the bone and the technique of the cement application. Evaluating radiolucency at the bone-cement interface at 1 year and 3 years postoperatively they found that rates of radiolucency adjacent to the tibial components of the knees that had been prepared with irrigation of the bone surfaces with a syringe and manual packing of the bone cement were not only higher than those in knees that had been prepared with high-pressure lavage of the bone surfaces and manual packing of the cement, but also when compared with knees that had been prepared with high-pressure lavage and pressure injection of low-viscosity

methylmethacrylate cement. However, they did not evaluate cement penetration, the study was not randomized, and the TKA analyzed was an all-polyethylene tibial plateau model.

In the present study, we evaluated cement penetration using the KSSS scale on AP and lateral plain X-rays. [19] The use of this scale and comparable methods [21] to assess cement penetration in plain X-rays has been recognized as a reliable method [21, 23], demonstrating up to 0.9 consistency for both interobserver and intraobserver agreement [23].

Our study has several limitations. One is related to variability in X-ray imaging as patient position may alter results. However, this bias was minimized by means of an X-ray protocol evaluating tibial plateau obliquity and assessing our results according to this. Another limitation could be the use of X-ray rather than CT; however, X-ray reduces patient radiation. Furthermore, the only scale available to date to evaluate bone cementation is the KSSS TKA bone cementation scale, and the number of published studies directly addressing cement penetration using this method is limited, which may restrict comparison with previous literature. The performance of all TKAs by a limited group of four surgeons may also be considered a potential limitation regarding external validity. Finally, our sample size was not based on previous studies in vivo following the same system, and a larger sample size may find statistically significant differences.

Conclusions

High-pressure pulsatile lavage did not demonstrate significant differences in enhancing bone cement penetration compared with manual lavage, as measured by the KSSS TKA bone cementation scale in X-rays taken on the first postoperative day.

Abbreviations

TKA	Total knee arthroplasty
KSSS	Knee society scoring system
AP	Anteroposterior

Acknowledgements

None.

Author contributions

Eduard Ramírez and Manel Fa designed the project; Eduard Ramírez, Manel Fa, Jorge Pilco, Xavier Aguilera, Jose Carlos González, and Marcos Jordan recruited the patients; Manel Fa and Jorge Pilco collected data; Eduard Ramírez, Manel Fa, and Jorge Pilco analyzed images; Eduard Ramírez, Manel Fa, and Jorge Pilco performed data analysis with the support of Ignasi Gich; Eduard Ramírez, Manel Fa, and Jorge Pilco wrote the paper with input from all the authors; and Eduard Ramírez led the project.

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Data availability

The datasets generated and analyzed during the current study are not publicly available due to restrictions imposed by the hospital ethics committee regarding patient data confidentiality.

Declarations

Ethics approval and consent to participate

The study was approved by the clinical research ethics committee at our institution (IIBSP-HPL-2021–90) and conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. Informed consent was obtained from all individual participants included in the study.

Consent for publication

All included patients provided informed consent for participation in the study and publication of the data.

Competing interests

The authors have no relevant financial or nonfinancial interests to disclose.

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References

- Lee SH, Kim DH, Lee YS (2020) Is there an optimal age for total knee arthroplasty? A systematic review. *Knee Surg Relat Res* 32:60. <https://doi.org/10.1186/s43019-020-00080-1>
- Park J, Chang MJ, Kim TW et al. (2024) Serial changes in patient-reported outcome measures and satisfaction rate during long-term follow-up after total knee arthroplasty: a systematic review and meta-analysis. *Knee Surg Relat Res* 36:43. <https://doi.org/10.1186/s43019-024-00241-6>
- Lizaur-Utrilla A, Miralles-Muñoz FA, Ruiz-Lozano M et al. (2021) Better clinical outcomes and overall higher survival with hybrid versus cemented primary total knee arthroplasty: a minimum 15 years follow-up. *Knee Surg Sports Traumatol Arthrosc Off J ESSKA* 29:832–837. <https://doi.org/10.1007/s00167-020-06028-y>
- Sharkey PF, Hozack WJ, Rothman RH et al. (2002) Why are total knee arthroplasties failing today? *Clin Orthop* 404:7–13. <https://doi.org/10.1097/00003086-200211000-00003>
- Cox ZC, Engstrom SM, Shinar AA et al. (2023) Is cement mantle thickness a primary cause of aseptic tibial loosening following primary total knee arthroplasty? *Knee* 40:305–312. <https://doi.org/10.1016/j.knee.2022.12.003>
- Peters CL, Craig MA, Mohr RA, Bachus KN (2003) Tibial component fixation with cement. *Clin Orthop* 409:158–168. <https://doi.org/10.1097/01.blo.0000058638.94987.20>
- Refsum AM, Nguyen UV, Gjertsen JE et al. (2019) Cementing technique for primary knee arthroplasty: a scoping review. *Acta Orthop* 90:582–589. <https://doi.org/10.1080/17453674.2019.1657333>
- Seeger JB, Jaeger S, Bitsch RG et al. (2013) The effect of bone lavage on femoral cement penetration and interface temperature during oxford unicompartmental knee arthroplasty with cement. *J Bone Jt Surg - Ser A* 95:48–53. <https://doi.org/10.2106/JBJS.K.01116>
- Boontanapibul K, Ruangsomboon P, Charoencholvanich K, Pornrat-tanamaneeewong C (2016) Effectiveness testing of combined innovative pressurized carbon dioxide lavage and pulsatile normal saline irrigation to enhance bone cement penetration in total knee replacement: a cadaveric study. *J Med Assoc Thai* 99:1198–1202
- Clarius M, Seeger JB, Jaeger S et al. (2012) The importance of pulsed lavage on interface temperature and ligament tension force in cemented unicompartmental knee arthroplasty. *Clin Biomech* 27:372–376. <https://doi.org/10.1016/j.clinbiomech.2011.10.006>
- Helwig P, Konstantinidis L, Hirschl Müller A et al. (2013) Tibial cleaning method for cemented total knee arthroplasty: an experimental study. *Indian J Orthop* 47:18–22. <https://doi.org/10.4103/0019-5413.106887>
- Jaeger S, Seeger JB, Schulz C et al. (2013) Tibial cementing in UKA: a three-dimensional analysis of the bone cement implant interface and the effect of bone lavage. *J Arthroplasty* 28:191–194. <https://doi.org/10.1016/j.arth.2013.05.014>
- Schlegel UJ, Püschel K, Morlock MM, Nagel K (2014) An in vitro comparison of tibial tray cementation using gun pressurization or pulsed lavage. *Int Orthop* 38:967–971. <https://doi.org/10.1007/s00264-014-2303-4>
- Schlegel UJ, Siewe J, Delank KS et al. (2011) Pulsed lavage improves fixation strength of cemented tibial components. *Int Orthop*. <https://doi.org/10.1007/s00264-010-1137-y>
- Maistrelli GL, Antonelli L, Fornasier V, Mahomed N (1995) Cement penetration with pulsed lavage versus syringe irrigation in total knee arthroplasty. *Clin Orthop* 1:261–265
- Stannage K, Shakespeare D, Bulsara M (2003) Suction technique to improve cement penetration under the tibial component in total knee arthroplasty. *Knee* 10:67–73. [https://doi.org/10.1016/s0968-0160\(02\)00084-4](https://doi.org/10.1016/s0968-0160(02)00084-4)
- Clarius M, Hauck C, Seeger JB et al. (2009) Pulsed lavage reduces the incidence of radiolucent lines under the tibial tray of Oxford unicompartmental knee arthroplasty: pulsed lavage versus syringe lavage. *Int Orthop* 33:1585–1590. <https://doi.org/10.1007/s00264-009-0736-y>
- Ritter MA, Herbst SA, Keating EM, Faris PM (1994) Radiolucency at the bone-cement interface in total knee replacement. The effects of bone-surface preparation and cement technique. *J Bone Jt Surg - Ser A* 76:60–65. <https://doi.org/10.2106/00004623-199401000-00008>
- Ewald FC, Society K (1989) The knee society total knee arthroplasty roentgenographic evaluation and scoring system. *Clin Orthop Relat Res* 248:9
- Wing N, Van Zyl N, Wing M et al. (2021) Reliability of three radiographic classification systems for knee osteoarthritis among observers of different experience levels. *Skeletal Radiol* 50:399–405. <https://doi.org/10.1007/s00256-020-03551-4>
- Jawhar A, Stetzelberger V, Kollowa K, Obertacke U (2019) Tourniquet application does not affect the periprosthetic bone cement penetration in total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 27:2071–2081. <https://doi.org/10.1007/s00167-018-5330-7>
- Kopec M, Milbrandt JC, Duellman T et al. (2009) Effect of hand packing versus cement gun pressurization on cement mantle in total knee arthroplasty. *Can J Surg* 52:490–494. [https://doi.org/10.1016/S0008-428X\(09\)50188-9](https://doi.org/10.1016/S0008-428X(09)50188-9)
- Pfützner T, von Roth P, Voerkelius N et al. (2016) Influence of the tourniquet on tibial cement mantle thickness in primary total knee arthroplasty. *Knee Surg Sports Traumatol Arthrosc* 24:96–101. <https://doi.org/10.1007/s00167-014-3341-6>
- Lutz MJ, Pincus PF, Whitehouse SL, Halliday BR (2009) The effect of cement gun and cement syringe use on the tibial cement mantle in total knee arthroplasty. *J Arthroplasty* 24:461–467. <https://doi.org/10.1016/j.arth.2007.10.028>
- Ozkunt O, Sariyilmaz K, Gemalmaz HC, Dikici F (2018) The effect of tourniquet usage on cement penetration in total knee arthroplasty. *Medicine (Baltimore)*. <https://doi.org/10.1097/md.0000000000009668>
- Sasaki R, Nagashima M, Tanaka K, Takeshima K (2024) Relationship between cement penetration and incidence of a radiolucent line around the tibia 2 years after total knee arthroplasty: a retrospective study. *J ISAKOS* 9:609–614. <https://doi.org/10.1016/j.jisako.2024.05.015>

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