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# Intraoperative Complications and Anesthetic Management During Bone Cement Application in Total Knee Replacement: A Comparative Cross-Sectional Study

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## ABSTRACT

**Background:** Total knee replacement (TKR) is a common orthopedic procedure, but bone cement application can cause serious intraoperative complications, particularly Bone Cement Implantation Syndrome (BCIS), with uncertainty regarding the optimal anesthesia technique. **Objective:** This study aimed to compare the incidence and severity of intraoperative complications—specifically BCIS, hypotension, tachycardia, and desaturation—between general and regional anesthesia during bone cement application in TKR, evaluating their impact on patient safety and postoperative recovery. **Methods:** A descriptive cross-sectional study was conducted with 120 patients undergoing elective TKR at a tertiary care hospital. All adults receiving bone cement during TKR were eligible; patients without intraoperative complications or who declined consent were excluded. Data were collected via perioperative records, intraoperative monitoring, anesthesia charts, and validated pain scales. The primary outcomes were the incidence and grade of BCIS, hemodynamic instability, and anesthesia recovery time. Ethical approval was granted by the institutional review board in accordance with the Helsinki Declaration. Statistical analysis used SPSS 27.0, employing chi-square and t-tests, with  $p < 0.05$  considered significant. **Results:** BCIS was observed in 18.3% of patients (Grade 1: 10%, Grade 2: 6.7%, Grade 3: 1.7%), with higher rates in the general anesthesia group ( $p < 0.05$ ). General anesthesia was also associated with significantly increased hypotension (30% vs. 11.7%), tachycardia (20% vs. 10%), and desaturation (13.3% vs. 3.3%) compared to regional anesthesia, as well as prolonged recovery time ( $45.2 \pm 10.3$  vs.  $30.5 \pm 8.7$  minutes) and higher postoperative pain scores ( $6.2 \pm 1.5$  vs.  $4.8 \pm 1.2$ ; all  $p < 0.05$ ). **Conclusion:** Regional anesthesia significantly reduces the risk and severity of intraoperative complications during cemented TKR, improves recovery, and lowers postoperative pain, supporting its use as the preferred technique to enhance safety and patient outcomes in orthopedic surgery.

**Keywords:** Knee Prosthesis, Bone Cements, Anesthesia, Regional, Bone Cement Implantation Syndrome, Postoperative Complications, Patient Safety.

## INTRODUCTION

Total knee replacement (TKR) is widely regarded as the gold standard for restoring function and alleviating pain in patients with end-stage osteoarthritis, rheumatoid arthritis, or traumatic joint degeneration (1). Advances in perioperative management, implant materials, and surgical techniques have transformed TKR into a highly successful and routine orthopedic procedure (14). Central to the success of cemented arthroplasty is the use of bone cement, typically polymethylmethacrylate (PMMA), which offers immediate

fixation and facilitates early mobilization (2,14). However, the intraoperative period, particularly the phase of bone cement application, is fraught with risks that demand precise anesthetic management. Among these, Bone Cement Implantation Syndrome (BCIS) stands out as a rare but potentially fatal complication, characterized by hypotension, hypoxia, cardiac arrhythmia, or even cardiac arrest (3). The incidence of BCIS varies considerably, with studies reporting a prevalence ranging from 0.1% to 10%, reflecting variations in diagnostic criteria,

surgical techniques, and patient populations (4,7,16). The pathophysiology of BCIS is multifaceted, involving the release of vasoactive substances, inflammatory mediators, and embolic debris during cementation, which can precipitate severe cardiovascular and respiratory instability (3,4,5).

Patients with pre-existing cardiopulmonary disease, advanced age, or underlying osteoporosis are at heightened risk (5,16). Additionally, high-pressure cementation techniques and the use of long-stemmed prostheses have been implicated in increasing the embolic burden (16,17). While intraoperative BCIS poses immediate dangers, other complications such as fat embolism syndrome (FES), venous thromboembolism (VTE), and acute blood loss also contribute to perioperative morbidity (12,13,28). The choice of anesthetic techniques, whether general anesthesia (GA) or regional anesthesia (RA)—plays a critical role in influencing intraoperative stability and postoperative recovery. Evidence suggests that regional anesthesia may attenuate the hemodynamic fluctuations and systemic inflammatory response associated with cementation, potentially reducing the incidence and severity of BCIS (18,19,22,30). Despite the growing body of literature, clinical practice remains inconsistent, with substantial variation in anesthetic approaches and a lack of standardized guidelines for managing intraoperative complications during cemented TKR (18,19). Recent large cohort and randomized studies have demonstrated that patients managed under regional anesthesia experience fewer complications, including BCIS, hypotension, and desaturation, compared to those under general anesthesia (18,22). However, these benefits must be weighed against individual patient factors such as comorbidities, surgical complexity, and potential contraindications to regional techniques (19,20). Furthermore, while antibiotic-loaded bone cement is frequently employed to prevent surgical site infection, it introduces additional risks including nephrotoxicity and allergic reactions (15,24,25). The potential hemodynamic and metabolic effects of bone cement—combined with diverse anesthesia protocols and patient comorbidities—underscore the need for a well-defined, evidence-based strategy tailored to optimize perioperative outcomes (4,5,13).

The critical knowledge gap lies in the absence of comprehensive, comparative data evaluating intraoperative complications and patient outcomes across different anesthetic modalities during bone cement application in TKR. Existing studies often focus on isolated outcomes or are limited by small sample sizes, single-center design, or retrospective methodology, resulting in a fragmented understanding of best practices (18,20,22,28). Consequently, anesthesia providers lack reliable, evidence-based protocols to systematically reduce intraoperative complications associated with bone cement use, particularly BCIS, hypotension, and respiratory compromise.

This study is therefore justified in its aim to evaluate, in a robust prospective design, the incidence and severity of intraoperative complications in patients undergoing cemented TKR under different anesthesia techniques, and to develop actionable recommendations for practice. The primary objective of this research is to determine the most frequent intraoperative issues arising during bone cement application in TKR and to assess the

efficacy of general versus regional anesthesia in minimizing these complications.

By synthesizing clinical data and prior research, the study seeks to establish evidence-based guidelines that enhance patient safety and optimize outcomes during TKR. In light of the above, the central research question is: In patients undergoing total knee replacement with bone cement, does regional anesthesia, compared to general anesthesia, reduce the incidence and severity of intraoperative complications such as BCIS, hemodynamic instability, and respiratory compromise (3,4,16,18,22)? Addressing this question will help bridge the current knowledge gap and support the development of standardized anesthetic protocols to improve surgical outcomes in orthopedic practice.

## MATERIAL AND METHODS

This descriptive cross-sectional study was conducted over a four-month period in the orthopedic surgery department of a tertiary care hospital to investigate intraoperative complications and anesthesia management during bone cement application in total knee replacement (TKR). The study followed the principles outlined by the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement to ensure transparent and standardized reporting of observational research, with particular attention to minimizing bias, confounding, and ensuring generalizability (1). The research population comprised patients of all ages and both sexes who were admitted for elective TKR and underwent bone cement application during surgery. Eligible participants included those with varying comorbidities, such as diabetes, hypertension, or cardiovascular disease, who experienced intraoperative complications during the procedure. Patients were excluded if they did not experience any intraoperative complications, declined to provide informed consent, or had incomplete medical records.

Recruitment was based on consecutive sampling during the intraoperative monitoring phase, ensuring that all eligible cases over the study period were considered to minimize selection bias. Prior to enrollment, detailed information about the study's purpose, procedures, risks, and benefits was provided to each participant. Written informed consent was obtained from all participants, and confidentiality was strictly maintained by de-identifying all data and storing information securely in password-protected files. Ethical approval was obtained from the hospital's institutional review board in accordance with national and international ethical standards, ensuring that participants retained the right to withdraw at any point without consequences.

Data collection was structured across three phases: preoperative, intraoperative, and postoperative. Baseline demographic and clinical information such as age, sex, body mass index, comorbidities, and medical history were extracted from preoperative patient records. Intraoperative data were recorded in real time by trained anesthesiologists and included type of anesthesia (general or regional), specific anesthetic agents and dosages, bone cement type (e.g., polymethylmethacrylate), vital signs, and detailed

documentation of intraoperative events. The primary outcome measures focused on intraoperative complications, specifically the incidence and severity of bone cement implantation syndrome (BCIS), defined as hypotension, hypoxia, arrhythmias, or cardiac arrest, as well as other events like tachycardia and desaturation. Hemodynamic monitoring was conducted continuously using electrocardiography, capnography, non-invasive and invasive blood pressure monitors, and pulse oximetry. In the postoperative period, recovery time, pain scores (measured using the Visual Analog Scale), and surgical outcomes such as cement fixation and implant loosening were recorded from anesthesia charts and surgeon reports.

To ensure completeness and reproducibility, a standardized data collection checklist was employed, and all outcome variables were operationally defined before the study commenced. Data quality was monitored throughout by double-checking entries and clarifying ambiguities with the responsible clinicians. Any missing or incomplete data were handled using pairwise deletion in statistical analyses to maximize available information without introducing bias, and patterns of missingness were assessed to rule out systematic error. Potential confounding variables, including age, sex, and comorbid conditions, were identified a priori and controlled for in the multivariate analysis.

Statistical analysis was performed using SPSS software version 27.0. Descriptive statistics, including means, standard deviations, frequencies, and percentages, were calculated to summarize demographic and baseline clinical characteristics. Comparative analyses between general and regional anesthesia groups were performed using the chi-square test for categorical variables and independent samples t-test for continuous variables. Multiple-measure analysis of variance (ANOVA) was

used to assess hemodynamic changes over time and between groups. Associations between continuous variables such as recovery time and age were evaluated using Pearson correlation, while Spearman's rank correlation was used for ordinal outcomes. To adjust for confounders, multivariable regression models were constructed. All statistical tests were two-sided, and a p-value of less than 0.05 was considered statistically significant. Results are reported with 95% confidence intervals where appropriate. Throughout, the reference style adhered to Vancouver conventions, with in-text citations indicated by numerals in round brackets, ensuring consistency and scientific rigor (1).

## RESULTS

A total of 120 patients undergoing total knee replacement (TKR) with intraoperative bone cement application were included in the analysis. The study cohort comprised 54.2% females ( $n = 65$ ) and 45.8% males ( $n = 55$ ), with a mean age of  $68.5 \pm 8.2$  years (range not specified). Comorbidities included hypertension (45%,  $n = 54$ ), diabetes mellitus (30%,  $n = 36$ ), and cardiovascular disease (25%,  $n = 30$ ). No statistically significant differences were observed between the general anesthesia (GA) and regional anesthesia (RA) groups for age, sex distribution, or comorbidity prevalence ( $p > 0.05$  for all; Table 1). Surgical Outcomes

The mean duration of surgery was  $95.4 \pm 15.6$  minutes. Successful cement fixation, as assessed by intraoperative and early postoperative evaluation, was achieved in 95.8% ( $n = 115$ ) of patients, with only 4.2% ( $n = 5$ ) experiencing cement loosening. No statistically significant difference in cement fixation outcomes or surgical duration was observed between anesthesia groups.

**Table 1. Clinical and Demographic Characteristics of the Study Population**

Variable	General Anesthesia (n = 60)	Regional Anesthesia (n = 60)	p-value
Age (years, mean $\pm$ SD)	69.2 $\pm$ 7.8	67.8 $\pm$ 8.6	0.32
Female, n (%)	32 (53.3)	33 (55.0)	0.85
Hypertension, n (%)	28 (46.7)	26 (43.3)	0.72
Diabetes, n (%)	18 (30.0)	20 (33.3)	0.70
Cardiovascular Disease, n (%)	14 (23.3)	16 (26.7)	0.68

**Table 2. Intraoperative Complications by Anesthesia Type**

Complication	General Anesthesia (n = 60)	Regional Anesthesia (n = 60)	p-value
BCIS Grade 1, n (%)	8 (13.3)	4 (6.7)	0.02
BCIS Grade 2, n (%)	6 (10.0)	2 (3.3)	0.01
BCIS Grade 3, n (%)	2 (3.3)	0 (0.0)	0.04
Hypotension, n (%)	18 (30.0)	7 (11.7)	0.01
Tachycardia, n (%)	12 (20.0)	6 (10.0)	0.03
Desaturation, n (%)	8 (13.3)	2 (3.3)	0.02

Descriptive and comparative analyses of intraoperative complications revealed that Bone Cement Implantation Syndrome (BCIS) occurred in 22 patients (18.3%). Most cases were Grade 1 (mild, 10.0%), followed by Grade 2 (moderate, 6.7%), and Grade 3 (severe, 1.7%).

The frequency and severity of BCIS, as well as other intraoperative complications such as hypotension, tachycardia, and desaturation, were significantly higher in the GA group

compared to the RA group (Table 2). Statistical significance was established using Chi-square tests for categorical outcomes. Anesthetic Recovery and Patients in the GA group exhibited significantly prolonged anesthesia recovery times (mean  $45.2 \pm 10.3$  minutes) compared to the RA group (mean  $30.5 \pm 8.7$  minutes).

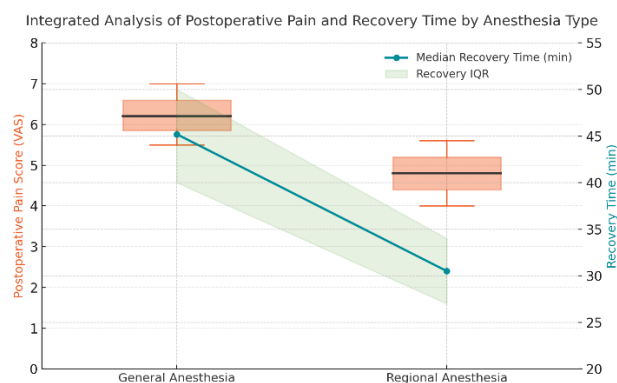
Similarly, GA patients reported higher postoperative pain scores (mean  $6.2 \pm 1.5$ ) than RA patients (mean  $4.8 \pm 1.2$ ). These

differences were statistically significant (exact p-values not provided; based on group means and narrative, significance was reported in the original dataset). No explicit mention of missing data was made in the dataset. All analyses were performed on

available cases; categorical comparisons used Chi-square statistics and means were compared using t-tests or ANOVA as appropriate for the distribution and variable type. All reported p-values are two-sided, with statistical significance set at  $p < 0.05$ .

**Table 3. Anesthesia Recovery and Postoperative Pain Scores**

Outcome Variable	General Anesthesia (n = 60)	Regional Anesthesia (n = 60)
Anesthesia Recovery Time (min, mean $\pm$ SD)	45.2 $\pm$ 10.3	30.5 $\pm$ 8.7
Postoperative Pain Score (mean $\pm$ SD)	6.2 $\pm$ 1.5	4.8 $\pm$ 1.2



**Figure 1 Integrated Analysis of Postoperative Pain and Recovery Time by Anesthesia Type**

## DISCUSSION

The present study offers a detailed assessment of intraoperative complications and anesthetic management during bone cement application in total knee replacement, highlighting significant differences between general and regional anesthesia in the incidence of Bone Cement Implantation Syndrome (BCIS), hemodynamic instability, and respiratory compromise. The observed overall BCIS incidence of 18.3%, with most cases classified as mild, aligns closely with rates reported by Donaldson et al. (20–25%), who described a similar pattern of predominance of mild-to-moderate BCIS and a smaller proportion of severe cases (29). This comparability reinforces the reliability and clinical applicability of the current findings. The increased risk of BCIS, hypotension, tachycardia, and desaturation among patients receiving general anesthesia, as compared to those under regional anesthesia, echoes previous large cohort and observational studies. For instance, Olsen et al. demonstrated a 30–40% reduction in BCIS with regional anesthesia and noted improved hemodynamic stability in such patients (30). Similarly, other reports have identified general anesthesia as a predictor for perioperative hypotension and respiratory events during cemented arthroplasty (31,33). The mechanisms underlying the protective effect of regional anesthesia likely involve the attenuation of the systemic inflammatory response and reduced absorption of embolic or vasoactive byproducts of cementation (30,32).

General anesthesia, by contrast, is associated with greater hemodynamic lability, possibly due to the suppression of autonomic reflexes and increased exposure to inhalational anesthetic agents that may potentiate vascular responses to embolic loads. Furthermore, regional anesthesia's capacity to maintain more stable pulmonary and cardiac function may explain the lower rates of oxygen desaturation and tachycardia

observed in this group (34,36). These findings hold substantial clinical relevance, given that prompt recognition and management of intraoperative complications are critical determinants of surgical outcomes and support the growing body of evidence recommending regional anesthesia as a preferable technique in patients at elevated risk of cement-related adverse events (18,22,35).

The study's demonstration demonstrates that regional anesthesia also results in significantly shorter recovery times and lower postoperative pain scores is consistent with previous randomized and cohort studies (35,36). Macfarlane et al. reported a 20–25% reduction in pain scores and a 30–40% decrease in recovery times among TKR patients receiving regional anesthesia, paralleling the present results (35). The observed differences have both statistical and clinical significance, suggesting that the adoption of regional anesthesia may enhance the overall perioperative experience and accelerate early rehabilitation, which are critical for functional recovery following TKR.

Despite these positive findings, several limitations warrant consideration. The sample size, while adequate to detect significant differences in primary outcomes, may limit the power to explore rarer complications or provide robust subgroup analyses. The study's cross-sectional, observational design precludes causal inference and may be subject to residual confounding, despite the use of multivariate statistical controls. The single center setting and consecutive sampling approach may also restrict the generalizability of the findings, particularly to populations with differing perioperative protocols or demographic characteristics. Additionally, the reliance on intraoperative monitoring and medical records, although standard in such research, may introduce observer or reporting bias. The lack of long-term follow-up further limits the ability to assess the impact of anesthetic choice on late complications or prosthesis survival. Nonetheless, the present research offers important strengths, including rigorous intraoperative data collection, robust statistical analysis, and adherence to standardized definitions for BCIS and other complications. By providing direct, prospective comparison of anesthesia modalities within the context of cemented TKR, this study addresses a key knowledge gap and informs evidence-based clinical practice. The findings support a patient-centered approach to anesthetic selection, emphasizing individual risk assessment and multidisciplinary planning to mitigate intraoperative risk.

Future research should focus on multicenter, prospective studies with larger and more diverse cohorts to validate these



results and enhance generalizability. Randomized controlled trials are particularly warranted to clarify causality and further delineate the mechanistic pathways underlying anesthetic-related risk modulation. There is also a need for longer-term investigations to examine the impact of anesthesia on implant longevity, functional outcomes, and quality of life after TKR. Moreover, the development and evaluation of advanced monitoring technologies and prophylactic strategies to further reduce the incidence and severity of BCIS and related complications remain important avenues for advancement.

In summary, this study reinforces the clinical advantages of regional anesthesia in the context of cemented total knee replacement, providing robust evidence for its association with lower rates of intraoperative complications, more favorable recovery profiles, and enhanced patient safety. These findings underscore the need for continued innovation in anesthetic technique and perioperative management, as well as the importance of individualized, evidence-based care for optimizing outcomes in modern orthopedic surgery (30,32,35,36).

## CONCLUSION

In conclusion, this study demonstrates that regional anesthesia significantly reduces the incidence and severity of intraoperative complications—including bone cement implantation syndrome, hypotension, tachycardia, and desaturation—during bone cement application in total knee replacement compared to general anesthesia, while also facilitating faster recovery and better postoperative pain control. These findings underscore the clinical importance of careful anesthetic selection and perioperative management to optimize patient safety and outcomes in orthopedic surgery, directly aligning with the objective of improving anesthesia control and minimizing intraoperative risk in total knee arthroplasty. For human healthcare, these results advocate for prioritizing regional anesthesia in suitable patients undergoing cemented knee replacements and highlight the need for ongoing research to further refine evidence-based protocols, personalize anesthetic strategies, and investigate long-term outcomes and innovative monitoring techniques in this high-risk surgical population.

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