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Hemodynamic Effects and Complications of Bone Cement Utilization in Orthopedic Operations

Yashar Eslampoor [1], Naghi Abedini[2*]

[1]Assistant Professor of A1nesthesiology, Department of Anesthesiology, School of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran

[2]Associate Professor of Anesthesiology, Department of Anesthesiology, School of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran

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ABSTRACT

Introduction: In contemporary orthopedic practice, bone cement continues to play a vital role in achieving successful surgical outcomes and improving patient mobility and quality of life. Nevertheless, its utilization is accompanied by important physiological effects that demand careful consideration. Hemodynamic changes associated with bone cement application represent a significant perioperative challenge due to their unpredictable nature and potential severity.

Material and methods: This prospective observational study was conducted at Shohada Hospital in 2025 to evaluate hemodynamic changes and complications associated with bone cement use during orthopedic surgery. A total of 200 patients were enrolled through convenience sampling. Perioperative cardiovascular and respiratory parameters were continuously monitored and recorded at predefined intervals.

Results: Among 200 patients undergoing cemented orthopedic surgery, hypotension was the most common intraoperative complication (29.00%), followed by tachycardia (20.50%) and hypertension (17.00%). Suspected Bone Cement Implantation Syndrome (BCIS) occurred in 11.00% of cases, while severe Grade 3 BCIS was identified in 1.00% of patients. Hemodynamic complications were significantly associated with older age, higher ASA class, cardiovascular comorbidities, prolonged surgery duration, and the use of general anesthesia.

Conclusion: Bone cement utilization in orthopedic procedures is associated with clinically important hemodynamic alterations and varying degrees of BCIS. Although most complications were transient and manageable, elderly patients and those with significant comorbidities demonstrated a higher risk of perioperative instability.

Introduction

Orthopedic surgery has undergone remarkable advances over the past several decades, particularly with the widespread use of bone cement in joint arthroplasty and other reconstructive procedures. Polymathic methacrylate (PMMA), commonly referred to as bone cement, has become an essential component in modern orthopedic practice because of its ability to provide immediate implant fixation, enhance prosthetic stability, and improve postoperative functional outcomes (1). Cemented fixation techniques are frequently employed in hip and knee arthroplasties, vertebroplasty, kyphoplasty, and the management of pathological fractures, especially among elderly patients with poor bone quality (2). Despite the considerable benefits associated with bone cement utilization, increasing attention has been directed toward its systemic physiological effects and the potentially serious complications that may occur during or shortly after cement implantation (3).

Corresponding Author: **Naghi Abedini (abedini-naghi@yahoo.com - ORCID: 0000-0002-1671-0432)*
1 Email: dr_dr_tabriz@yahoo.com - ORCID: 0000-0002-9056-4250)

Among these concerns, hemodynamic instability represents one of the most clinically significant challenges encountered by anesthesiologists and orthopedic surgeons during cemented orthopedic procedures (4).

The administration of bone cement during orthopedic operations is associated with a spectrum of cardiovascular and pulmonary responses that can range from mild transient alterations in blood pressure and heart rate to severe life-threatening events (5). These changes may include hypoxia, hypotension, cardiac arrhythmias, elevated pulmonary vascular resistance, right ventricular dysfunction, cardiac arrest, and sudden intraoperative death. The occurrence of these events has led to growing concern regarding the safety profile of bone cement, particularly in vulnerable patient populations such as the elderly, individuals with cardiovascular disease, and patients undergoing emergency orthopedic interventions (6). The increasing global prevalence of degenerative joint disease and the expanding aging population have contributed to a rise in the number of cemented arthroplasty procedures performed annually, thereby emphasizing the importance of understanding the hemodynamic consequences associated with bone cement application (7).

One of the most recognized complications related to bone cement use is Bone Cement Implantation Syndrome (BCIS), a potentially fatal perioperative phenomenon characterized by hypoxia, hypotension, pulmonary hypertension, cardiac arrhythmias, and loss of consciousness. BCIS most commonly occurs during cementation, prosthesis insertion, joint reduction, or limb tourniquet release. Although the exact incidence of BCIS varies across studies and depends on the definition and grading system employed, mild forms are relatively common, whereas severe manifestations occur less frequently but carry substantial morbidity and mortality (8). The syndrome is particularly associated with cemented hip hemiarthroplasty procedures performed for femoral neck fractures in elderly patients. In these individuals, advanced age, reduced cardiopulmonary reserve, osteoporosis, and multiple comorbid conditions may increase susceptibility to adverse hemodynamic events during surgery (9).

The pathophysiology underlying hemodynamic alterations following bone cement utilization is complex and multifactorial. Several mechanisms have been proposed to explain the cardiovascular and pulmonary disturbances observed during cemented orthopedic procedures. One important theory involves embolization of intramedullary contents into the circulation during cement pressurization and prosthesis insertion (10). High intramedullary pressures generated during these stages can force fat, bone marrow debris, air, cement particles, and aggregates of platelets into the venous system. These embolic materials may subsequently migrate to the pulmonary vasculature, causing mechanical obstruction, increased pulmonary artery pressure, impaired gas exchange, and acute right ventricular strain. In severe cases, significant reductions in cardiac output and systemic arterial pressure may occur, leading to cardiovascular collapse (11).

In addition to embolic phenomena, the direct pharmacological and toxic effects of methyl methacrylate monomer have also been implicated in the development of hemodynamic instability. Absorption of methyl methacrylate into the systemic circulation may produce vasodilation and decreased systemic vascular resistance, thereby contributing to hypotension. Experimental studies have suggested that the monomer may exert negative inotropic effects on myocardial tissue and influence vascular smooth muscle tone. Although improvements in cement preparation techniques and modern formulations have reduced monomer exposure compared with earlier decades, concerns regarding its physiological effects continue to exist. Furthermore, the exothermic polymerization process associated with bone cement curing may contribute to local tissue injury and inflammatory responses (12).

Another important mechanism contributing to perioperative hemodynamic changes is the activation of inflammatory and vasoactive mediators. Cementation and embolic events can trigger the release of histamine, serotonin, thromboxane, complement factors, and other cytokines that influence pulmonary and systemic vascular tone (13). These mediators may exacerbate pulmonary vasoconstriction and increase capillary permeability, thereby worsening hypoxia and cardiopulmonary dysfunction. The interaction between embolic obstruction, inflammatory activation, and preexisting cardiopulmonary impairment likely determines the severity of clinical manifestations observed in affected patients (140).

Several patient-related and procedure-related risk factors have been identified in association with adverse hemodynamic events during cemented orthopedic surgery. Advanced age remains one of the most significant predictors because elderly patients frequently possess diminished physiological reserve and a higher prevalence of chronic cardiovascular and pulmonary diseases. Patients with congestive heart failure, coronary artery disease, pulmonary hypertension, chronic obstructive pulmonary disease, or impaired ventricular function may be less capable of tolerating sudden circulatory changes induced by cement implantation (15). Hypovolemia, osteoporosis, pathological fractures, and metastatic bone disease may also increase intramedullary vascular exposure and embolic load during surgery. From a procedural perspective, femoral canal pressurization, long-stem prostheses, inadequate medullary lavage, and bilateral cemented procedures have been associated with increased risk of BCIS and related complications (16).

Anesthetic management plays a crucial role in the recognition, prevention, and treatment of hemodynamic disturbances associated with bone cement use. Continuous cardiovascular monitoring and early detection of physiological alterations are essential for reducing perioperative morbidity and mortality. Anesthesiologists must remain vigilant during critical stages of surgery, particularly during femoral reaming, cement insertion, prosthesis placement, and joint reduction (170). Both general and regional anesthesia techniques have been used successfully in cemented orthopedic procedures; however, each approach presents specific advantages and limitations regarding hemodynamic monitoring and physiological stability. Adequate preoperative optimization, maintenance of intravascular volume, administration of supplemental oxygen, and clear communication between the surgical and anesthesia teams are considered essential preventive strategies (18).

Surgical techniques aimed at minimizing intramedullary pressure and embolic release have also been developed to reduce the incidence and severity of cement-related complications. These methods include thorough medullary canal lavage, venting of the femoral canal, use of low-viscosity cement, retrograde cement insertion, and careful prosthesis positioning. Improvements in prosthesis design and cementing techniques have contributed to enhanced safety outcomes over time. Nonetheless, despite technological and procedural advances, hemodynamic instability associated with bone cement remains a clinically important concern that necessitates ongoing investigation and vigilance (19).

The clinical manifestations of hemodynamic alterations following bone cement utilization can vary considerably in severity and duration. Mild cases may present as transient decreases in oxygen saturation or blood pressure that resolve with supportive treatment, whereas severe cases can rapidly progress to cardiovascular collapse requiring aggressive resuscitation. The timing of symptom onset is often closely related to cementation or prosthesis insertion, making intraoperative awareness particularly important. In some patients, postoperative complications such as respiratory failure, myocardial injury, prolonged intensive care admission, or delayed recovery may occur as a consequence of intraoperative hemodynamic compromise. Therefore, understanding the mechanisms and predictors of these complications is essential for improving perioperative outcomes (20).

Recent studies have sought to better characterize the incidence, pathophysiology, and preventive measures associated with bone cement-related hemodynamic disturbances. Advances in intraoperative monitoring, including trans esophageal echocardiography and pulmonary artery catheterization, have provided valuable insights into embolic events and cardiovascular responses during cemented procedures. Research has demonstrated that embolic material can frequently be detected intraoperatively, even in patients without clinically significant symptoms, suggesting that subclinical embolization may occur commonly during orthopedic surgery. This finding highlights the importance of differentiating between physiological changes that are transient and clinically insignificant and those that may progress to severe complications (21).

The ongoing debate regarding cemented versus uncemented prosthetic fixation further underscores the relevance of understanding bone cement-associated complications. Cemented prostheses often provide superior fixation, improved load distribution, and reduced postoperative pain, particularly in elderly patients with osteoporotic bone. Conversely, uncemented implants may reduce the risk of BCIS and intraoperative hemodynamic instability but may not always achieve equivalent long-term stability in certain patient populations. Consequently, the decision regarding fixation technique should involve careful evaluation of patient characteristics, surgical indications, and perioperative risk factors (22).

Given the potentially serious consequences of hemodynamic instability during orthopedic surgery, continued research is necessary to establish evidence-based strategies for risk assessment, prevention, and management. Greater awareness among healthcare professionals regarding the early signs of BCIS and related complications may contribute to improved patient safety and outcomes. Multidisciplinary collaboration between orthopedic surgeons, anesthesiologists, perioperative nurses, and critical care teams is essential for optimizing perioperative care in patients undergoing cemented orthopedic procedures (23).

In contemporary orthopedic practice, bone cement continues to play a vital role in achieving successful surgical outcomes and improving patient mobility and quality of life. Nevertheless, its utilization is accompanied by important physiological effects that demand careful consideration. Hemodynamic changes associated with bone cement application represent a significant perioperative challenge due to their unpredictable nature and potential severity. A comprehensive understanding of the mechanisms, risk factors, clinical manifestations, and preventive approaches related to these complications is fundamental for minimizing adverse outcomes and enhancing the safety of orthopedic surgical interventions. As the number of orthopedic procedures continues to increase worldwide, particularly among elderly and medically complex patients, the importance of recognizing and managing bone cement-related hemodynamic effects will remain a critical aspect of perioperative medicine and orthopedic care.

Material and methods

Study Design

This prospective observational study was conducted with the aim of determining the hemodynamic effects and complications associated with bone cement utilization during orthopedic operations. The study was carried out at Shohada Hospital, affiliated with Tabriz University of Medical Sciences, during the year 2025. The primary objective of the investigation was to evaluate perioperative hemodynamic changes following bone cement application and to identify the frequency and nature of related intraoperative and postoperative complications among patients undergoing cemented orthopedic procedures.

Sampling Method

Participants were recruited using a convenience sampling method from eligible patients admitted to the orthopedic surgery wards of Shohada Hospital. A total of 200 patients who met the study eligibility criteria and were scheduled for orthopedic operations involving bone cement implantation were enrolled consecutively during the study period.

Eligibility Criteria

Adult patients aged 18 years and older who were scheduled to undergo elective or emergency orthopedic procedures requiring the use of polymathic methacrylate bone cement, including hip arthroplasty, knee arthroplasty, hemiarthroplasty, and other cemented orthopedic interventions, were considered eligible for inclusion in the study. Both male and female patients with the ability to provide informed consent or whose legal guardians were able to consent on their behalf were included. Patients were required to have complete preoperative medical records and stable baseline hemodynamic parameters before surgery. Individuals were excluded if they underwent orthopedic procedures without bone cement utilization, had severe preoperative hemodynamic instability requiring vasopressor support, suffered from advanced uncontrolled cardiac arrhythmias, severe decompensated heart failure, active septic shock, or terminal systemic disease with a life expectancy of less than three months. Patients with documented hypersensitivity to bone cement components, severe cognitive impairment preventing reliable data collection, incomplete perioperative records, withdrawal of consent, or intraoperative conversion to a non-cemented procedure were also excluded from the study. Additionally, patients who experienced major traumatic hemorrhage unrelated to cement implantation during surgery or those requiring simultaneous major surgical interventions were not included in the final analysis to minimize potential confounding factors affecting hemodynamic assessment.

Procedure

After obtaining informed consent, eligible patients undergoing cemented orthopedic surgery were enrolled consecutively and evaluated throughout the perioperative period. Demographic data including age, sex, body mass index, smoking status, underlying comorbidities, medication history, and preoperative laboratory findings were recorded using a standardized data collection form. Baseline cardiovascular and respiratory parameters, including systolic blood pressure, diastolic blood pressure, mean arterial pressure, heart rate, respiratory rate, oxygen saturation, and electrocardiographic findings, were documented before anesthesia induction. Information related to the type of orthopedic procedure, indication for surgery, anesthesia technique, duration of surgery, type and volume of bone cement used, prosthesis characteristics, estimated blood loss, and intraoperative fluid administration was also collected. Continuous hemodynamic monitoring was performed during surgery using standard anesthesia monitoring systems. Hemodynamic parameters were specifically recorded at predefined intervals, including before anesthesia induction, immediately before cement insertion, during cementation, during prosthesis implantation, immediately after implantation, and at regular postoperative intervals in the recovery unit. Any significant hemodynamic alterations such as hypotension, hypertension, tachycardia, bradycardia, arrhythmias, oxygen desaturation, pulmonary complications, cardiac arrest, or manifestations suggestive of Bone Cement Implantation Syndrome were documented carefully by the anesthesia and research teams. The severity of complications was assessed according to standard clinical criteria, and all interventions performed to stabilize patients, including oxygen therapy, fluid resuscitation, vasopressor administration, cardiopulmonary resuscitation, or intensive care admission, were recorded. Patients were subsequently followed during their postoperative hospitalization period to evaluate early postoperative complications, duration of hospital stay, and immediate surgical outcomes. To ensure consistency and reduce observational bias, all measurements were obtained by trained personnel using calibrated monitoring equipment and standardized protocols throughout the study period. Data confidentiality was maintained during all stages of data collection and analysis, and all patient identifiers were removed before statistical evaluation.

Statistical Analysis
Data analysis was performed using Statistical Package for the Social Sciences (SPSS) software version 26. Quantitative variables were expressed as mean ± standard deviation or median and interquartile range depending on data distribution, while qualitative variables were presented as frequencies and percentages. The normality of continuous variables was assessed using the Kolmogorov–Smirnov test. Paired t-test or repeated measures analysis of variance (ANOVA) was used to compare hemodynamic parameters at different time points for normally distributed data, whereas nonparametric alternatives including the Wilcoxon signed-rank test or Friedman test were applied for non-normally distributed variables. Independent t-test and chi-square test were used for comparisons between groups when appropriate. Logistic regression analysis was performed to identify factors associated with the occurrence of significant hemodynamic complications and Bone Cement Implantation Syndrome.

Ethical Considerations
The present study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and approved by the Ethics Committee of Tabriz University of Medical Sciences under the ethical approval code IR.TBZMED.REC.1403.244. Written informed consent was obtained from all participants or their legal representatives before enrollment in the study. Participants were assured that their personal information and medical records would remain strictly confidential and would be used solely for research purposes. All collected data were anonymized prior to statistical analysis to protect patient privacy. Participation in the study was entirely voluntary, and patients were allowed to withdraw from the study at any stage without any effect on the quality of their medical care or treatment process.

Results
A total of 200 patients undergoing cemented orthopedic procedures were included in the present study. The mean age of the participants was 68.42 ± 11.37 years, with a mean body mass index of 27.18 ± 4.26 kg/m². Among the study population, 112 patients (56.00%) were male and 88 patients (44.00%) were female. A history of smoking was reported in 61 patients (30.50%). Regarding preoperative physical status classification, 74 patients (37.00%) were categorized as ASA II, 96 patients (48.00%) as ASA III, and 30 patients (15.00%) as ASA IV. Hypertension was the most common comorbidity, affecting 103 patients (51.50%), followed by diabetes mellitus in 67 patients (33.50%), ischemic heart disease in 42 patients (21.00%), and chronic obstructive pulmonary disease in 29 patients (14.50%). Hip arthroplasty represented the most frequently performed procedure, accounting for 91 cases (45.50%), while knee arthroplasty and hemiarthroplasty were performed in 64 (32.00%) and 45 patients (22.50%), respectively. In terms of anesthetic technique, spinal anesthesia was administered in 118 patients (59.00%), whereas 82 patients (41.00%) underwent surgery under general anesthesia (table 1).

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

Variable	Value
Age (years), mean ± SD	68.42 ± 11.37
BMI (kg/m²), mean ± SD	27.18 ± 4.26
Male, n (%)	112 (56.00)
Female, n (%)	88 (44.00)
Smoking status, n (%)	61 (30.50)
ASA Physical Status, n (%)	-
ASA II	74 (37.00)
ASA III	96 (48.00)
ASA IV	30 (15.00)
Comorbidities, n (%)	-
Hypertension	103 (51.50)
Diabetes Mellitus	67 (33.50)
Ischemic Heart Disease	42 (21.00)
COPD	29 (14.50)
Type of Surgery, n (%)	-
Hip Arthroplasty	91 (45.50)
Knee Arthroplasty	64 (32.00)
Hemiarthroplasty	45 (22.50)
Type of Anesthesia, n (%)	-
General Anesthesia	82 (41.00)
Spinal Anesthesia	118 (59.00)

Preoperative assessment of baseline hemodynamic parameters demonstrated relatively stable cardiovascular and respiratory status among the enrolled patients prior to surgery. The mean systolic blood pressure was 132.46 ± 15.28 mmHg, while the mean diastolic blood pressure was 78.64 ± 10.17 mmHg. The average mean arterial pressure was calculated at 96.58 ± 11.42 mmHg. In addition, the mean preoperative heart rate was 81.37 ± 12.54 beats per minute, indicating acceptable baseline cardiac function in the majority of participants. Peripheral oxygen saturation levels were also within normal physiological range, with a mean SpO_2 value of 96.84 ± 1.92%. Overall, these findings suggest that most patients entered the operative setting with relatively preserved hemodynamic stability before anesthesia induction and bone cement application (figure 1).

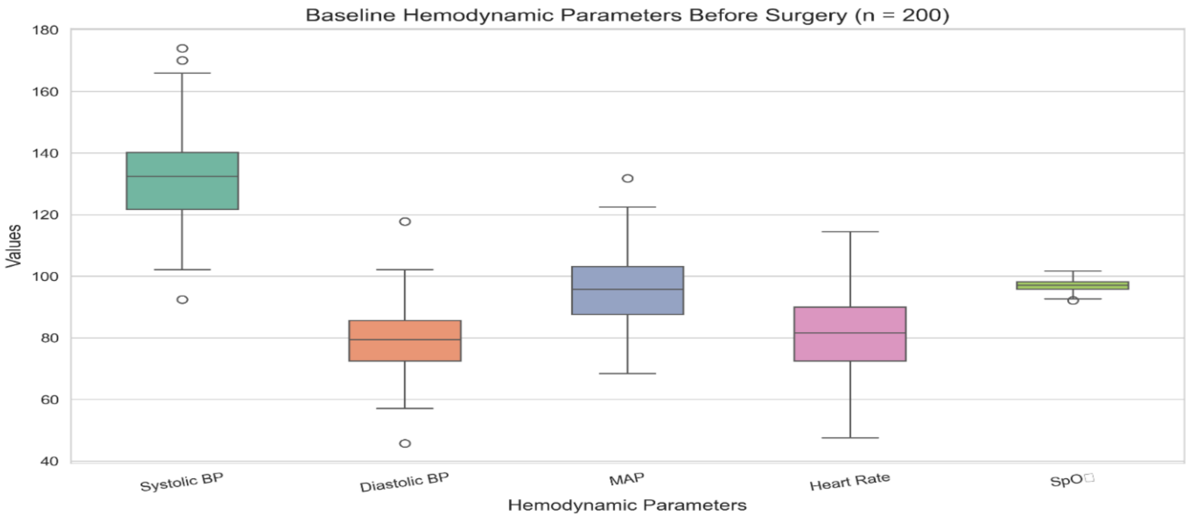

Figure 1. Baseline Hemodynamic Parameters Before Surgery

Table 2 demonstrates the frequency of intraoperative hemodynamic complications observed during orthopedic procedures involving bone cement utilization. Hypotension was identified as the most prevalent adverse event, affecting 29.00% of patients, indicating that transient reductions in blood pressure were relatively common during surgery. Tachycardia and hypertension were also frequently encountered, occurring in 20.50% and 17.00% of cases, respectively. Oxygen desaturation was reported in 13.50% of patients, reflecting the potential respiratory and cardiopulmonary effects associated with cement implantation. Suspected Bone Cement Implantation Syndrome (BCIS) was observed in 11.00% of the study population. In contrast, severe complications such as pulmonary complications, arrhythmias, and cardiac arrest occurred less frequently. Overall, the findings suggest that although most complications were manageable and transient, clinically significant hemodynamic instability remains an important perioperative concern in cemented orthopedic surgeries.

Table 2. Frequency of Intraoperative Hemodynamic Complications

Complication	n (%)
Hypotension	58 (29.00%)
Hypertension	34 (17.00%)
Tachycardia	41 (20.50%)
Bradycardia	19 (9.50%)
Arrhythmia	14 (7.00%)
Oxygen desaturation	27 (13.50%)
Pulmonary complications	11 (5.50%)
Cardiac arrest	3 (1.50%)
Suspected BCIS	22 (11.00%)

Table 3 summarizes the severity grading of Bone Cement Implantation Syndrome (BCIS) in patients undergoing cemented orthopedic procedures. Most patients showed no clinical evidence of BCIS and were categorized as Grade 0, accounting for 89.00% of the study population. Grade 1 BCIS, characterized by moderate hypoxia or hypotension, was identified in 7.00% of patients and represented the most common symptomatic form of the syndrome. More severe manifestations, including pronounced hypoxia or hypotension consistent with Grade 2 BCIS, were observed in 3.00% of cases.

Grade 3 BCIS, defined by cardiovascular collapse, occurred infrequently and was recorded in only 1.00% of patients. Overall, the data demonstrate that while the majority of patients tolerated bone cement implantation without major complications, a clinically important subset experienced varying degrees of cardiopulmonary instability requiring careful perioperative monitoring and prompt management.

Table 3. Severity of Bone Cement Implantation Syndrome (BCIS)

BCIS Grade	Clinical Definition	Frequency (%)
Grade 0	No evidence of BCIS	178 (89.00%)
Grade 1	Moderate hypoxia or hypotension	14 (7.00%)
Grade 2	Severe hypoxia or hypotension	6 (3.00%)
Grade 3	Cardiovascular collapse	2 (1.00%)

Table 4 demonstrates significant differences between patients who developed intraoperative hemodynamic complications and those who remained hemodynamically stable during cemented orthopedic procedures. Patients in the complication group were significantly older than those without complications (71.84 ± 9.26 vs. 66.47 ± 10.13 years, P=0.002). A significantly greater proportion of these patients also had advanced ASA physical status (Class III–IV) (68.06% vs. 40.63%, P<0.001). Among comorbid conditions, hypertension (56.94% vs. 36.72%, P=0.006), diabetes mellitus (36.11% vs. 22.66%, P=0.041), and preexisting cardiovascular disease (43.06% vs. 21.88%, P=0.002) were all significantly more common in patients who experienced hemodynamic instability. Cemented hip arthroplasty was also associated with a significantly higher rate of complications compared with other surgical procedures (54.17% vs. 33.59%, P=0.005). Furthermore, the mean duration of surgery was significantly longer in the complication group (124.58 ± 21.44 minutes vs. 108.37 ± 18.92 minutes, P<0.001). General anesthesia was more frequently administered among patients with complications (63.89% vs. 46.09%, P=0.015). However, no statistically significant association was observed between patient sex and the occurrence of hemodynamic complications (P=0.482). Overall, these findings suggest that older age, higher ASA classification, underlying comorbidities, prolonged operative duration, and general anesthesia may contribute to an increased risk of intraoperative hemodynamic disturbances following bone cement utilization.

Table 4. Comparison Between Patients with and Without Hemodynamic Complications

Variable	Complication (n=72)	No Complication (n=128)	P-value
Age (years)	71.84 ± 9.26	66.47 ± 10.13	0.002
Male sex, n (%)	38 (52.78%)	61 (47.66%)	0.482
ASA Class III–IV, n (%)	49 (68.06%)	52 (40.63%)	<0.001
Hypertension, n (%)	41 (56.94%)	47 (36.72%)	0.006
Diabetes mellitus, n (%)	26 (36.11%)	29 (22.66%)	0.041
Cardiovascular disease, n (%)	31 (43.06%)	28 (21.88%)	0.002
Cemented hip arthroplasty, n (%)	39 (54.17%)	43 (33.59%)	0.005
Duration of surgery (min)	124.58 ± 21.44	108.37 ± 18.92	<0.001
General anesthesia, n (%)	46 (63.89%)	59 (46.09%)	0.015

Discussion

The present study demonstrated that the use of bone cement during orthopedic procedures was associated with a considerable incidence of intraoperative hemodynamic disturbances, although most patients maintained acceptable baseline cardiovascular stability prior to surgery. Transient hypotension emerged as the most frequent complication, followed by tachycardia, hypertension, and oxygen desaturation. In addition, a clinically relevant proportion of patients developed manifestations compatible with Bone Cement Implantation Syndrome (BCIS), ranging from mild hemodynamic compromise to severe cardiovascular collapse. Patients who experienced complications were generally characterized by advanced age, higher perioperative risk profiles, greater burden of comorbid disease, longer operative duration, and increased exposure to general anesthesia. Collectively, these findings emphasize that while cemented orthopedic surgery is routinely performed and often well tolerated, significant cardiopulmonary instability may still occur in susceptible individuals and requires careful perioperative attention.

The relatively stable baseline hemodynamic profile observed in the current study indicates that most patients entered surgery without major preexisting circulatory instability. This finding is clinically important because it suggests that many of the observed intraoperative disturbances were likely related to perioperative physiological stressors and the biological effects of bone cement implantation rather than severe baseline cardiovascular dysfunction alone. Cemented orthopedic procedures, particularly arthroplasty operations, are known to induce rapid physiological alterations during cement pressurization and prosthesis insertion. These alterations can affect both systemic vascular resistance and cardiopulmonary performance, especially in elderly individuals with reduced physiological reserve (24).

Hypotension was identified as the most common intraoperative complication in this study. This observation is consistent with previous orthopedic and anesthesiology literature describing transient blood pressure reduction as the hallmark hemodynamic response following cement implantation. Several mechanisms may explain this phenomenon. One of the most widely accepted explanations involves embolization of fat, marrow debris, air, and cement particles into the venous circulation during intramedullary pressurization. These embolic materials may travel to the pulmonary vasculature and produce acute increases in pulmonary vascular resistance. As right ventricular afterload rises, right ventricular dysfunction may develop, leading to reduced left ventricular preload and subsequent systemic hypotension. In severe cases, this sequence may progress to circulatory collapse characteristic of advanced BCIS (25).

In addition to embolic mechanisms, the vasoactive properties of methyl methacrylate monomer may also contribute to hemodynamic instability. Absorption of the monomer into the bloodstream has been associated with peripheral vasodilation and myocardial depression in experimental investigations. Although the precise contribution of monomer toxicity remains debated, transient vasodilation combined with reduced cardiac output may partially explain the hypotensive episodes observed during cemented procedures. Furthermore, anesthetic agents themselves may amplify these effects by suppressing sympathetic tone and diminishing compensatory cardiovascular responses (26).

Tachycardia represented another frequent finding in the present study and likely reflected a compensatory physiological response to reductions in blood pressure and cardiac output. Acute sympathetic activation during periods of hemodynamic stress may increase heart rate in an attempt to preserve tissue perfusion. Surgical stimulation, pain responses, hypoxia, and anxiety may also contribute to perioperative tachycardia. In some patients, tachycardia may have been related to catecholamine release triggered by hypoxemia or pulmonary vascular obstruction following embolic events. Although often transient, sustained tachycardia can increase myocardial oxygen demand and may be clinically significant in elderly patients with underlying coronary artery disease (27).

Hypertension was also observed in a notable proportion of patients. Unlike hypotension, perioperative hypertension may arise from nociceptive stimulation, inadequate anesthetic depth, or stress-induced sympathetic discharge during surgery. Some patients may experience fluctuating hemodynamic responses during cement implantation, with transient hypertensive episodes preceding later hypotension. Preexisting hypertension and arterial stiffness, which are common among elderly orthopedic patients, may further predispose individuals to exaggerated blood pressure variability during surgical manipulation (28).

Oxygen desaturation constituted another important finding and supports the cardiopulmonary effects associated with cement implantation. Reduced oxygen saturation during orthopedic surgery may result from ventilation–perfusion mismatch secondary to pulmonary embolization of marrow contents and cement particles. Obstruction of pulmonary microcirculation can impair gas exchange and increase intrapulmonary shunting. In addition, inflammatory mediator release during embolic events may promote pulmonary vasoconstriction and endothelial dysfunction, thereby worsening hypoxemia. The coexistence of hypoxia and hypotension is particularly characteristic of BCIS and may indicate significant cardiopulmonary compromise (29).

The observed incidence of suspected BCIS further reinforces the clinical relevance of this syndrome in cemented orthopedic surgery. Although most cases in the present study were classified as mild or moderate, severe forms associated with cardiovascular collapse were also identified. BCIS is believed to represent a multifactorial process involving embolic load, inflammatory activation, pulmonary vascular dysfunction, and impaired cardiovascular reserve. The predominance of lower-grade BCIS in this study may reflect improvements in modern anesthetic monitoring, surgical techniques, and perioperative optimization. Nonetheless, even mild BCIS may have important clinical implications in frail patients with limited cardiopulmonary reserve (30).

The finding that advanced age was significantly associated with intraoperative hemodynamic complications is biologically plausible and consistent with previous evidence. Aging is accompanied by progressive reductions in cardiovascular adaptability, impaired autonomic responsiveness, and diminished ventricular compliance. Elderly patients may therefore be less capable of compensating for sudden alterations in preload, afterload, and pulmonary vascular resistance during cement implantation. In addition, older individuals frequently possess multiple comorbidities that further compromise physiological reserve and increase susceptibility to perioperative instability.

Higher ASA physical status was also strongly associated with complications in the present study. ASA classification reflects the overall systemic health of the patient and indirectly represents baseline physiological resilience. Patients with advanced ASA grades often exhibit chronic cardiovascular, pulmonary, renal, or metabolic disorders that impair compensatory mechanisms during surgical stress. Consequently, these individuals may be more vulnerable to transient reductions in cardiac output, oxygenation abnormalities, and arrhythmogenic events associated with cement implantation (31).

Comorbid conditions such as hypertension, diabetes mellitus, and cardiovascular disease demonstrated significant relationships with hemodynamic instability. Chronic hypertension may lead to endothelial dysfunction, impaired vascular compliance, and altered auto regulatory responses, making patients more sensitive to abrupt hemodynamic fluctuations. Diabetes mellitus may contribute through autonomic neuropathy and microvascular impairment, both of which reduce the body’s ability to maintain circulatory stability under stress. Preexisting cardiovascular disease is particularly important because compromised myocardial function may limit the ability of the heart to tolerate acute increases in pulmonary vascular resistance or reductions in preload during embolic events (32).

The association between cemented hip arthroplasty and increased complication rates likely reflects the unique physiological burden imposed by this procedure. Hip arthroplasty often requires extensive intramedullary manipulation and high-pressure cement insertion, both of which increase the likelihood of embolic phenomena. The femoral canal contains abundant marrow contents that may become displaced into the circulation during prosthesis insertion. Consequently, hip arthroplasty has repeatedly been identified as one of the orthopedic procedures most strongly associated with BCIS and perioperative cardiopulmonary instability (33).

Longer operative duration was another significant predictor of complications in the current study. Prolonged surgery may increase cumulative physiological stress, fluid shifts, blood loss, and anesthetic exposure. Extended procedures may also indicate greater surgical complexity or technical difficulty, both of which can contribute to increased inflammatory responses and hemodynamic variability. In elderly or medically compromised patients, prolonged operative stress may progressively exhaust compensatory physiological mechanisms and increase the risk of instability (34).

General anesthesia was more frequently associated with complications than other anesthetic approaches. This finding may be related to the cardiovascular depressant effects of general anesthetic agents, including reduced systemic vascular resistance and impaired autonomic compensation. Positive-pressure ventilation during general anesthesia may additionally reduce venous return and exacerbate hemodynamic compromise in patients experiencing pulmonary embolic phenomena. In contrast, regional anesthesia may preserve spontaneous ventilation and attenuate stress responses in selected patients. However, the relationship between anesthesia type and BCIS remains complex, and multiple confounding factors, including surgical selection and patient comorbidity profiles, must also be considered (35).

The relatively low incidence of severe complications such as cardiac arrest and major pulmonary events is encouraging and may indicate improvements in perioperative management strategies. Modern orthopedic and anesthetic practices increasingly emphasize early risk stratification, invasive hemodynamic monitoring in high-risk patients, optimized intravascular volume management, and careful cementation techniques. Measures such as medullary canal lavage, venting techniques, and gradual cement pressurization may help reduce embolic burden during surgery. Enhanced communication between surgeons and anesthesiologists during cement implantation is also essential for early recognition and prompt treatment of hemodynamic deterioration (36).

The findings of this study possess important clinical implications. Identification of high-risk patients before surgery may allow implementation of preventive strategies aimed at reducing perioperative morbidity. Elderly patients, individuals with advanced ASA classification, and those with significant cardiovascular comorbidities may benefit from intensified monitoring and optimization before undergoing cemented procedures. Continuous hemodynamic surveillance during cement implantation is particularly important because rapid intervention may prevent progression from mild instability to severe BCIS (37).

Several limitations should also be acknowledged. The study design may limit the ability to establish definitive causal relationships between bone cement utilization and observed complications. In addition, variations in surgical technique, anesthetic management, and perioperative monitoring protocols may have influenced the frequency and severity of complications. Future multicenter prospective studies with larger sample sizes and standardized monitoring strategies are needed to further clarify the mechanisms, predictors, and preventive approaches associated with BCIS and intraoperative hemodynamic instability (38).

Conclusion

In conclusion, the present study demonstrates that bone cement utilization in orthopedic surgery is associated with a spectrum of intraoperative hemodynamic complications, ranging from transient hypotension to severe cardiopulmonary compromise. Although most patients tolerated the procedure without major adverse events, clinically significant instability occurred more frequently among elderly individuals, patients with higher ASA status, those with underlying comorbidities, and patients undergoing prolonged cemented hip arthroplasty under general anesthesia. These findings highlight the importance of vigilant perioperative monitoring, careful patient selection, and preventive intraoperative strategies to minimize the risk of BCIS and related hemodynamic disturbances during cemented orthopedic procedures.

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Conflicts of interest

The authors declare that they have no competing interests.

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Authors' Contributions

All authors contributed to data analysis, drafting, and revising of the paper and agreed to be responsible for all the aspects of this work.

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