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Original Article

Anaesthesia Section

# Evaluation of Haemodynamic Changes in Patients undergoing Total Knee Arthroplasty under Regional Anaesthesia: A Prospective Observational Study

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## ABSTRACT

**Introduction:** Total Knee Arthroplasty (TKA) is a routinely used procedure for the management of knee osteoarthritis. Various haemodynamic changes can occur during TKA, especially during cementing and tourniquet deflation, which can have a significant impact on the patient's clinical condition. This study emphasises the importance of close haemodynamic monitoring for the timely detection of potential complications during this procedure.

**Aim:** To evaluate the haemodynamic changes occurring during spinal anaesthesia, bone cementation, and tourniquet deflation using Transthoracic Echocardiography (TTE) along with routine non invasive haemodynamic monitors in patients undergoing TKA.

**Materials and Methods:** The present study was a prospective, observational single-arm study conducted at a tertiary care centre from February 2019 to March 202.Thirty patients of either sex, belonging to American Society of Anaesthesiologists physical status I (aged between 40-70 years) and scheduled for TKA under regional anaesthesia, were enrolled in the study. Heart Rate (HR), Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), $SpO_2$ levels, respiratory rate, and End-Tidal $CO_2$ ($EtCO_2$) were recorded at various time intervals, including baseline value, after spinal anaesthesia, before cement implantation, after cement implantation, before tourniquet deflation, after tourniquet deflation, and at the end of the surgery. Blood gas analysis and TTE were recorded preoperatively, five minutes after cementation, and five minutes after tourniquet deflation. Data were collected and analysed using Student's t-test for continuous variables and Chi-square test or Fisher's exact test for nominal categorical variables. Statistical analysis was performed using the SPSS statistical package (version SPSS 17.0).

**Results:** The mean age, weight, and height of the patients were 54.46±6.78 years, 66.43±5.31 kg, and 152.5±7.71 cm, respectively. The mean HR increased from 82.27±6.11 beats/minute to 101.43±5.23 and 104.33+4.70 beats/minute after three and six minutes of cementation (p-value=0.001). The mean SBP increased from 121.67 mmHg to 144.13 mmHg and 138.87 mmHg after three and six minutes of cementation (p-value=0.001). The preoperative mean pH was 7.44, which decreased to 7.39 at five minutes after cement implantation and 7.38 after five minutes of tourniquet deflation (p-value=0.001). The preoperative mean $PaCO_2$ value was 44.83 mmHg, which increased to 62.30 mmHg after five minutes of cement implantation and 55.17 mmHg after five minutes of tourniquet deflation (p-value <0.05).

**Conclusion:** There was a significant increase in HR, blood pressure, and $PaCO_2$, as well as a decrease in pH after bone cement implantation. However, TTE performed at various time points did not suggest any significant changes during TKA. Hence, this study demonstrates that routine haemodynamic monitoring is sufficient, and no additional monitoring like ECHO is required in ASA 1 patients undergoing TKA.


**Keywords:** Arthroplasty, Echocardiography, End tidal $CO_2$, Tourniquet deflation

## INTRODUCTION

TKA has become the standard of care for older patients with end-stage osteoarthritis of the knee and is also indicated for some sports-related injuries. TKA is associated with substantial functional improvement and pain relief [1,2]. The various complications of TKA include Bone Cement Implantation Syndrome (BCIS), Pulmonary Embolism (PE), blood loss, and tourniquet-related nerve injuries [3]. During the TKA procedure, the mixing of poly-methyl methacrylate powder with liquid methyl-methacrylate (components of bone cement) leads to polymerisation, which involves the cross-linking of polymer chains. This further leads to an exothermic reaction that causes cement hardening and expansion against the prosthesis and bone. This may result in increased intramedullary pressure, leading to the embolisation of fat, bone marrow, cement, and air into the venous channels. These emboli can reach the pulmonary vasculature, causing Bone Cement Implantation Syndrome (BCIS). BCIS is characterised by hypoxia, hypotension, and unexpected loss of consciousness occurring around the time of cementation, prosthesis insertion, joint reduction, and limb tourniquet deflation in patients undergoing cemented arthroplasty [4,5].

Patients undergoing TKA have an increased risk of developing thromboembolism. Symptomatic pulmonary embolism has been reported to occur in upto 7% of patients undergoing TKA without prophylaxis, with a fatality rate of 2%. Patients undergoing major surgery, lower limb fractures, and hip and knee replacements are particularly prone to developing pulmonary embolism and venous thromboembolism [6]. Anaesthesiologists may find themselves responsible for the diagnosis and management of this fatal disorder. Common presenting symptoms in awake patients include dyspnoea, anxiety, loss of consciousness, and tachypnoea, while hypotension, tachycardia, hypoxemia, and decreased $EtCO_2$ are commonly observed in patients under general anaesthesia [7]. Given the high mortality rate associated with pulmonary embolism, greater attention should be given to preoperative anticoagulation and diagnostic workup to prevent venous thromboembolism.

Echocardiography (ECHO) is a helpful tool in diagnosing pulmonary embolism during cemented knee arthroplasty. The traditional diagnostic algorithm for pulmonary embolism involves the use of Computed Tomography (CT) scans. However, the logistics involved in safely transporting these patients can make these investigations cumbersome and pose a danger to their lives. ECHO can provide reliable information at the bedside, aiding in the selection of a management strategy for unstable patients. Without ECHO, hypotension or tachycardia may alert the anaesthetist to haemodynamic disturbances, but these signs do not indicate the cause. There are numerous signs and parameters described for pulmonary embolism on ECHO, including RV dilatation >1:1 (normal ratio of right to left ventricle is <0.6:1), right ventricular systolic dysfunction, McConnell's sign, moderate to severe tricuspid regurgitation, paradoxical septal wall motion, pulmonary artery dilatation, atrial dilatation, right heart thrombus, and lack of respiratory variation of the Inferior Vena Cava (IVC) [8].

Both Transthoracic Echocardiography (TTE) and Transoesophageal Echocardiography (TOE) provide direct assessment of ventricular volume and function. Unlike TOE, TTE can be used in non intubated patients during surgery and is less likely to interfere with airway management or other resuscitation procedures. TTE is non invasive, quicker, and does not require sedation or lengthy cleaning procedures [9-11].

The aim of this study was to evaluate the haemodynamic changes during spinal anaesthesia, bone cementation, and tourniquet deflation in TKA patients using TTE along with routine non invasive haemodynamic monitors. Haemodynamic monitoring of these patients during the perioperative period helps in the early detection and prompt management of any catastrophic events, thereby minimising morbidity and mortality.

## MATERIALS AND METHODS

The prospective observational single-arm study was conducted in the Department of Anaesthesia at Pt. BDS PGIMS Rohtak, after obtaining approval from the local Institutional Ethical Committee (IEC) (IEC/Th/18/Anst15) and following CTRI registration (CTRI/2020/05/025111). A total of 30 patients scheduled for unilateral cemented TKA (under regional anaesthesia) were enrolled in this study after obtaining informed consent. The study was conducted from February 2019 to March 2020.

**Inclusion criteria:** Patients age between 40-70 years, ASA physical status I, normal echo window were included in the study.

**Exclusion criteria:** Patients on contraindications to regional anaesthesia (local site infections and haemodynamic coagulation abnormality), allergy to amide local anaesthetics, pulmonary hypertension, coronary artery disease, valvular heart disease uncontrolled diabetes mellitus and hypertension, refusal to participate in the study, signs of RV hypertrophy were excluded from the study.

**Sample size:** For sample size calculation, a relevant difference of 10 in mean pulse rate post-cementation from baseline was defined. With an effect size of 0.44, a two-tailed alpha value of 0.05, and a beta value of 0.1, a sample size of 29 patients was determined to be sufficient to detect a significant difference.

The formula for calculating the sample size was as follows:

$(Z\alpha+Z\beta)^2/(\text{mean difference/SD})^2=(1.960+1.282)^2/0.44=13.02/0.44=29.6$. Therefore, a total of 30 patients were selected for the study.

### Procedure

All patients underwent a detailed history, complete physical, and systemic examination before surgery. Patient's age, weight, and height were recorded. Routine investigations such as haemoglobin, bleeding time, clotting time, urine examination, blood urea, blood sugar, renal function tests, serum electrolytes, chest X-ray, electrocardiograph, and any other specific investigations as per patient requirement were performed. All routine investigations were within normal limits. The purpose and protocol of the study were explained to the patients, and informed written consent was obtained. Patients were kept fasting for 6 hours prior to the scheduled time of surgery. They were premeditated with tab alprazolam 0.25 mg on the night before surgery.

Upon patient arrival in the operating room, routine monitoring was performed, including Non Invasive Blood Pressure Monitoring (NIBP), ECG, and pulse oximetry ($SpO_2$). An intravenous line was secured with an 18 G venous cannula, and appropriate fluid was started. Oxygen was administered via a simple face mask at a rate of 6 litres per minute to all patients. $EtCO_2$ tubing was attached to the mask and monitored throughout the operative procedure. Patients received regional anaesthesia (spinal or epidural anaesthesia) according to standard practice, and surgery commenced. Two patients required intraoperative conversion to general anaesthesia and were subsequently excluded from the study.

**The following observations were recorded:**

1) Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), HR, respiratory rate, oxygen saturation ($SpO_2$), and $EtCO_2$ were recorded at the following time intervals:
   - Baseline before spinal anaesthesia
   - 5 minutes, 10 minutes after spinal anaesthesia
   - Just before cement implantation
   - 3, 6, 12, and 15 minutes after cement implantation
   - Just before tourniquet deflation
   - 3, 6, 12, and 15 minutes after tourniquet deflation
2) Blood gas analysis (to record pH and $PaCO_2$) was performed at the following time intervals:
   - Preoperative (baseline)
   - 5 minutes after cement implantation
   - 5 minutes after tourniquet deflation
3) TTE assessment was conducted to look for any embolic episodes during the operative procedure at the following time intervals:
   - Preoperative (baseline)
   - 5 minutes after cement implantation
   - 5 minutes after tourniquet deflation

The time of spinal anaesthesia, incision, tourniquet inflation, cementation, tourniquet release, and skin closure was recorded to assist in identifying the cause of embolic events. Any perioperative complications such as hypotension, bradycardia, dyspnoea, nausea, and vomiting were noted and managed according to standard guidelines.

## STATISTICAL ANALYSIS

Statistical analysis was performed using the SPSS statistical package (version SPSS 17.0). Continuous variables were presented as mean±SD or median if the data was unevenly distributed. Categorical variables were expressed as frequencies and percentages. The comparison of continuous variables between groups was performed using Student's t-test. Nominal categorical data between groups were compared using the Chi-square test or Fisher's exact test, as appropriate. Non normally distributed continuous variables were compared using the Mann-Whitney U test. A p-value <0.05 was considered statistically significant for all tests.

## RESULTS

**Demographic profile:** The total number of patients in the present study was 30, with 20 females (66.7%) and 10 males (33.3%). The mean age, weight, and height of the patients were 54.46±6.78 years, 66.43±5.31 kg, and 152.5±7.71 cm, respectively. All parameters of the demographic profile were comparable [Table/Fig-1].

**Haemodynamic parameters:** A comparison of mean HR showed a statistically significant decrease in HR (72.07±5.884 and 75.80±6.815 at 5 and 10 minutes, respectively) after spinal anaesthesia compared

| | Minimum | Maximum | Mean±Std. Dev |
|---|---|---|---|
| Age (years) | 40.00 | 72.00 | 54.46±6.78 |
| Weight (kg) | 58.00 | 80.00 | 66.43±5.31 |
| Height (cm) | 138.00 | 170.00 | 152.5±7.71 |

**[Table/Fig-1]:** Demographic data.

to baseline values (82.27±7.460) [Table/Fig-2,3]. There was a significant decrease in SBP and DBP after spinal anaesthesia with a p-value <0.05 [Table/Fig-3]. No significant change was noted in $SpO_2$, respiratory rate, and $EtCO_2$ during spinal anaesthesia [Table/Fig-4,5].

A comparison of HR before and after cementation showed a significant increase in HR with a p-value <0.05 [Table/Fig-6]. There was also a significantly higher SBP and DBP after cement implantation (p-value <0.05) [Table/Fig-7]. No significant change was observed in $SpO_2$ and respiratory rate during cement implantation [Table/Fig-8]. $EtCO_2$ values significantly increased during cement implantation [Table/Fig-9].

A comparison of HR before and after tourniquet deflation revealed a significant decrease in HR after tourniquet deflation [Table/Fig-10]. Results showed no significant change in SBP, DBP, and $EtCO_2$ after tourniquet deflation [Table/Fig-11].

The mean pH in blood gas analysis preoperatively was 7.44, which decreased to 7.39 after five minutes of cement implantation and 7.38 after five minutes of tourniquet deflation. A comparison of the results showed statistically significant differences [Table/Fig-12]. The mean $PaCO_2$ levels on blood gas analysis preoperatively were 44.83 mmHg, which increased to 62.30 mmHg after five minutes of cement implantation and 55.17 mmHg after five minutes of tourniquet deflation. A comparison of $PaCO_2$ levels in blood gas analysis before spinal anaesthesia/preoperatively with values after cement implantation and tourniquet deflation showed an increase in $PaCO_2$ values (p-value <0.05) [Table/Fig-12].

**Trans Thoracic Echocardiography (TTE) Findings:** No significant findings suggestive of any embolic event during TKA were observed in the study subjects. TTE was performed at three time intervals: preoperatively before spinal anaesthesia, after the cementing process, and after tourniquet deflation. No right atrial or right ventricular dilatation or pulmonary artery dilatation was seen at any step during TKR. No features suggestive of right ventricular systolic dysfunction or thrombus in the right heart chambers were observed. No echocardiographic features suggestive of Mc Connell sign were seen. The IVC collapsibility index was normal in all cases, and there was normal respiratory variation of the IVC.

| Various time intervals | Heart Rate (HR) (beats/minutes) (Mean±SD) | Baseline vs specific time interval (p-value*) | Comparison of HR before and after spinal anaesthesia (p-value#) |
|---|---|---|---|
| Before spinal anaesthesia | 82.27±7.460 | | 0.001 (S) |
| 5 min after spinal anaesthesia | 72.07±5.884 | 0.001 (S) | |
| 10 min spinal anaesthesia | 75.80±6.815 | 0.001 (S) | |

**[Table/Fig-2]:** Comparison of Heart Rate (HR) during spinal anaesthesia.
*Paired student t-test, #Anova test

| Various time intervals of spinal anaesthesia | Systolic BP (mmHg) Mean±SD | Baseline vs specific time interval (p-value*) | Comparison of SBP before and after spinal anaesthesia (p-value#) | Diastolic BP (mmHg) Mean±SD | Baseline vs specific time interval (p-value*) | Comparison of DBP before and after spinal anaesthesia (p-value#) |
|---|---|---|---|---|---|---|
| Before spinal anaesthesia | 130.87±7.385 | | 0.001 (S) | 88.13±5.964 | | 0.001 (S) |
| 5 min after spinal anaesthesia | 113.93±8.542 | 0.001 (S) | | 78.53±9.157 | 0.001 (S) | |
| 10 min spinal anaesthesia | 117.47±7.628 | 0.001 (S) | | 82.07±7.728 | 0.001 (S) | |

**[Table/Fig-3]:** Comparison of Systolic Blood Pressure (SBP) and Diastolic Blood Pressure (DBP) at various time intervals during spinal anaesthesia.
*Paired student t-test, #Anova test

| Various time intervals of Total Knee Arthroplasty (TKA) | $SpO_2$ (Mean±SD) | *p-value | Respiratory rate (Mean±SD) | *p-value |
|---|---|---|---|---|
| Before spinal anaesthesia | 99.30±0.75 | 0.97 | 19.33±2.37 | 0.89 |
| 5 min after spinal anaesthesia | 99.77±0.51 | | 19.63±1.97 | |
| 10 min after spinal anaesthesia | 99.80±0.45 | | 19.47±2.39 | |

**[Table/Fig-4]:** Comparison of Oxygen Saturation ($SpO_2$) and respiratory rate during spinal anaesthesia.
*Paired student t-test

| Various time intervals of Total Knee Arthroplasty (TKA) | $EtCO_2$ (Mean±SD) | Comparison of End Tidal $CO_2$ ($EtCO_2$) before and after spinal anesthesia (p-value*) |
|---|---|---|
| Before spinal anaesthesia | 35.47±2.16 | 0.56 |
| 5 min after spinal anaesthesia | 34.87±2.15 | |
| 10 min after spinal anaesthesia | 35.80±1.61 | |

**[Table/Fig-5]:** Comparison of End Tidal $CO_2$ ($EtCO_2$) during spinal anaesthesia.
*Paired student t-test

| Various time intervals of Total Knee Arthroplasty (TKA) | HR (beats/minute) (Mean±Std. Dev) | Baseline vs specific time interval (p-value*) | Comparison of HR before and after cement implantation (p-value#) |
|---|---|---|---|
| Just before cement implantation | 82.87±6.118 | | 0.001 (S) |
| 3 min after cement implantation | 101.43±5.237 | 0.001 (S) | |
| 6 min after cement implantation | 104.33±4.700 | 0.001 (S) | |
| 12 min after cement implantation | 93.07±5.741 | 0.001 (S) | |
| 15 min after cement implantation | 88.93±6.291 | 0.001 (S) | |

**[Table/Fig-6]:** Comparison of Heart Rate (HR) after cement implantation.
*Paired student t-test, #Anova test

| Various time intervals of cement implantation | SBP (Mean±SD) | Baseline vs specific time interval (p-value*) | Comparison of SBP before and after cement implantation (p-value#) | DBP (Mean±SD) | Baseline vs specific time interval (p-value*) | Comparison of DBP before and after cement implantation (p-value#) |
|---|---|---|---|---|---|---|
| Just before cement implantation | 121.67±7.558 | | | 82.60±6.038 | | |
| 3 min after cement implantation | 144.13±5.406 | 0.001 (S) | | 94.33±5.202 | 0.001 (S) | |
| 6 min after cement implantation | 138.87±3.812 | 0.001 (S) | 0.001 (S) | 94.27±4.719 | 0.001 (S) | 0.001 (S) |
| 12 min after cement implantation | 132.67±4.678 | 0.001 (S) | | 88.87±5.296 | 0.004 (S) | |
| 15 min after cement implantation | 131.00±4.749 | 0.001 (S) | | 88.13±5.144 | 0.02 (S) | |

**[Table/Fig-7]:** Comparison of Systolic Blood Pressure (SBP) and Diastolic Blood Pressure (DBP) during various time intervals of cement implantation.
*Paired student t-test, #Anova test

| Various time intervals of Total Knee Arthroplasty (TKA) | $SpO_2$ (Mean±SD) | *p-value | Respiratory rate (Mean±SD) | *p-value |
|---|---|---|---|---|
| Just before cement implantation | 98.87±0.73 | | 19.50±2.55 | |
| 3 min after cement implantation | 98.70±0.53 | | 20.93±1.55 | |
| 6 min after cement implantation | 98.63±0.55 | 0.98 | 20.13±2.09 | 0.61 |
| 12 min after cement implantation | 98.77±0.56 | | 19.87±2.03 | |
| 15 min after cement implantation | 98.70±0.59 | | 20.53±2.67 | |

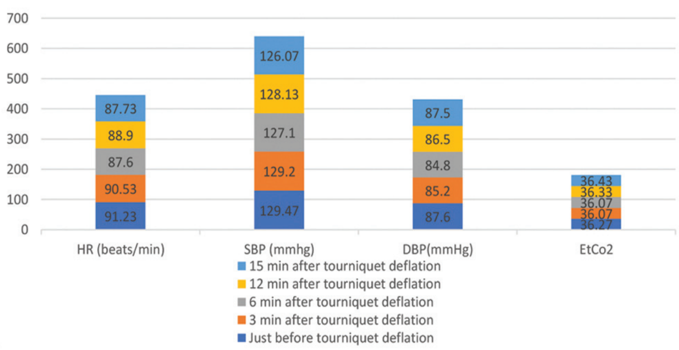
**[Table/Fig-8]:** Comparison of Oxygen Saturation ($SpO_2$) and respiratory rate during cement implantation.
*Paired student t-test

| Various time intervals of Total Knee Arthroplasty (TKA) | $EtCO_2$ (Mean±SD) | Baseline vs specific time interval (p-value*) | Comparison of $EtCO_2$ before and after cement implantation (p-value#) |
|---|---|---|---|
| Just before cement implantation | 35.80±2.427 | | |
| 3 min after cement implantation | 42.03±1.450 | 0.001 (S) | |
| 6 min after cement implantation | 41.53±1.717 | 0.001 (S) | 0.01 (S) |
| 12 min after cement implantation | 37.63±2.327 | 0.001 (S) | |
| 15 min after cement implantation | 36.33±1.398 | 0.56 | |

**[Table/Fig-9]:** Comparison of End tidal $CO_2$ ($EtCO_2$) during cement implantation.
*Paired student t-test, #Anova test

| Various time intervals of Total Knee Arthroplasty (TKA) | Heart Rate (HR) (Mean±SD) | Baseline vs specific time interval (p-value*) | Comparing HR before and after tourniquet deflation (p-value#) |
|---|---|---|---|
| Just before tourniquet deflation | 91.23±5.380 | | |
| 3 min after tourniquet deflation | 90.53±7.314 | 0.56 | |
| 6 min after tourniquet deflation | 87.60±3.692 | 0.01 (S) | 0.03 (S) |
| 12 min after tourniquet deflation | 88.90±5.333 | 0.02 (S) | |
| 15 min after tourniquet deflation | 87.73±5.343 | 0.02 (S) | |

**[Table/Fig-10]:** Comparison of Heart Rate (HR) before and after tourniquet deflation at various time intervals.
*Paired student t-test, #Anova test




**[Table/Fig-11]:** Comparison of vitals before and after tourniquet deflation at various time intervals.

| Various time intervals of Total Knee Arthroplasty (TKA) | pH (Mean±SD) | Comparison of pH at various time interval (p-value) | $PaCO_2$ (Mean±SD) | Comparison of $PaCO_2$ levels at different time intervals (p-value) |
|---|---|---|---|---|
| Preoperative | 7.44±0.03 | | 44.83±3.28 | |
| 5 min after cementing process | 7.39±0.05 | 0.001 (S) | 62.30±3.82 | 0.001 (S) |
| 5 min after tourniquet deflation | 7.38±0.04 | 0.001 (S) | 55.17±4.41 | 0.001 (S) |

**[Table/Fig-12]:** Comparison of pH and $PaCO_2$ levels on blood gas analysis during different surgical steps of Total Knee Arthroplasty (TKA).
Paired student t-test

## DISCUSSION

Various theories have been proposed to explain the changes that occur during bone cement implantation. An exothermic reaction occurs during cementation and prosthesis insertion, which expands the space between the prosthesis and bone, trapping air and debris. These emboli can be forced into the circulation due to high medullary pressure. These multiple emboli have both mechanical and mediator effects. Bone cement emboli may cause endothelial damage, leading to reflex vasoconstriction through the release of endothelial mediators, resulting in increased Pulmonary Vascular Resistance (PVR). Increased PVR, in the presence of decreased Right Ventricle (RV) preload, can result in a marked decrease in Cardiac Output (CO) and hypotension. However, not all changes can be explained by the embolus theory alone. Additional theories propose a direct hypersensitivity reaction to the cement, which can cause increased levels of C3a and C5a, resulting in smooth muscle contraction, histamine release, and increased vascular permeability. This can manifest clinically as pulmonary vasoconstriction, desaturation, and systemic hypotension [12,13].

In the present study, 30 patients undergoing TKA were monitored using TTE and blood gas analysis, along with routine haemodynamic monitors. The mean age of the included patients was 54.46±6.78 years, with 66.7% females and 33.3% males. All patients in the study were classified as ASA I physical status. The study focused on complications related to bone cement implantation, excluding pre-existing co-morbidities, so only ASA I patients were included. Various haemodynamic parameters were recorded during different steps of TKA and showed significant variability.

The HR showed significant variability during different steps of the surgical procedure. The HR was reduced after 5 minutes and 10 minutes of spinal anaesthesia compared to baseline values [Table/Fig-2]. This HR variability is an important factor in predicting systemic hypotension after spinal anaesthesia. The HR increased after the cementing process during TKA compared to before cementing values [Table/Fig-6]. The exothermic reaction may lead to an increase in HR. Qi X et al., also studied the effect of bone cement on the haemodynamics of elderly patients undergoing cemented arthroplasty and found an increase in HR but a fall in blood pressure [14].

In the present study, a slight decrease in blood pressure was observed after spinal anaesthesia compared to baseline values, which can be attributed to sympathetic system blockage after spinal anaesthesia [Table/Fig-3]. Previous studies have reported hypotension after bone cement implantation. Significant hypotension may occur if the right ventricle fails to compensate for an increase in PVR associated with prosthesis insertion. These changes are more pronounced in patients with poor cardiopulmonary reserve [14,15]. The present study included patients with good cardiopulmonary reserve, so these effects were not observed. Moreover, a slight increase in SBP was noted after bone cement implantation [Table/Fig-7]. These changes may be attributed to the exothermic reaction during the cementing process or an anaphylactic reaction.

Changes in $SpO_2$ were not significant in the present study, and there were no cases of pulmonary embolism in any patient. This may be due to the inclusion of patients with good cardiopulmonary reserve and supplemental oxygenation during the procedure, which can help mask minor changes. Milbrink J and Bergqvist D reported a decrease in $SpO_2$ after bone cementing, indicating that bone cement can have significant effects on the haemodynamics of patients undergoing cemented arthroplasty. An increase in PVR and ventilation-perfusion mismatch during bone cement implantation could be the cause of hypoxemia [7].

A sudden fall in $EtCO_2$ values can be indicative of an event like pulmonary embolism when other clinical features such as hypotension, breathlessness, and loss of consciousness are also present. Parmet JL et al., reported a decrease in $EtCO_2$ values after the cementing process in patients who experienced Bone Cement Implantation Syndrome (BCIS) [15]. In the present study, a significant increase in $EtCO_2$ values was noted after the cementing process [Table/Fig-9]. Similar increases in $PaCO_2$ pulmonary embolism values were also observed in blood gas analysis performed after five minutes of bone cementing [Table/Fig-12]. The decrease in pH observed corresponded to the increased $PaCO_2$ values in the blood gas analysis [Table/Fig-12]. Soleimanha M et al., also recorded a fall in pH after bone cementing, which is consistent with the findings of the present study [16].

In a study by Song I et al., arterial blood gas analysis showed a significant decrease in pH and arterial oxygen partial pressure ($PaO_2$) immediately after tourniquet deflation [17]. Arterial carbon dioxide partial pressure ($PaCO_2$) and lactate levels significantly increased immediately after tourniquet deflation. Townsend HS et al., reported maximum changes in arterial pH, $PaCO_2$, potassium, lactate, and bicarbonate concentration three minutes after tourniquet deflation [18].

To our knowledge, prior to this study, only one study reported an increase in $PaCO_2$ values after bone cementing, contrary to the belief that there would be a decrease in $PaCO_2$ values due to microemboli shower after bone cement implantation. Further studies with a larger number of patients are needed to investigate this effect, which may provide new insights into the effects of bone cement implantation. There were no other significant changes in the other parameters seen in the blood gas analysis in the present study.

Tourniquet inflation and deflation are important steps during TKA, as they can have significant haemodynamic effects on patients. There are instances where there is a decrease in $SpO_2$ or mean arterial pressures after tourniquet deflation, which may indicate an uneventful event like pulmonary embolism that needs to be managed immediately. In present study, there was no significant variation in blood pressures after tourniquet deflation [Table/Fig-11]. Song I et al., studied the haemodynamic and cerebral $SpO_2$ changes induced by tourniquet deflation in elderly patients during TKA and found a decrease in mean arterial pressures and cardiac output after tourniquet deflation [17]. Bharti N and Mahajan S reported a case of massive pulmonary embolism caused by the tourniquet ischaemia to the limb after tourniquet application [19].

Perioperative ECHO plays an important role in all surgeries by providing assistance in planning, decision-making, intraoperative evaluation, and postoperative management. TTE, being a non invasive technique, is helpful in the perioperative period and can aid in the diagnosis of many complications at the initial stages, leading to early intervention. In the present study, TTE was performed at different steps of TKA, such as before spinal anaesthesia (baseline), after the cementing process, and after tourniquet deflation. No significant findings suggestive of any embolic event during TKA were seen in present study subjects during TTE. This may be due to the inclusion of patients with good cardiorespiratory reserve and the smaller sample size.

### Limitation(s)

The sample size of the present study was relatively small, and only ASA I patients were included. Further studies with a larger sample size and patients with different characteristics are needed to demonstrate the usefulness of monitoring haemodynamic changes with TTE in patients undergoing TKA.

## CONCLUSION(S)

During the TKA operative procedure, there are various steps, especially during cementing, that can have a significant impact on the patient's haemodynamics and clinical condition. In this prospective study, although there were no cases of pulmonary embolism, there was a significant increase in HR, $EtCO_2$, $PaCO_2$, and a decrease in pH during the cementing process. Therefore, anaesthesiologists must be aware of these haemodynamic changes and be prepared to manage any complications that may arise during the procedure. This study demonstrates that routine haemodynamic monitoring is sufficient and additional monitoring, such as ECHO, is not required in ASA I patients with good cardiopulmonary reserve undergoing TKA.

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