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Hemodynamic changes in patients undergoing cemented total hip replacement surgery: a literature review

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ABSTRACT

Cemented total hip arthroplasty is believed to offer adequate pain relief, satisfactory walking ability, and activities of daily living as one of the most widely used techniques for treating hip fragility fractures. However, some complications may occur perioperatively, not to mention the catastrophic bone cement implantation syndrome. Thorough assessment, perioperative monitoring, early detection, and treatment plays an essential role to maximalize the result of this procedure, as well as minimalizing morbidity and mortality. Some anesthetic measures that can be done in order to keep the stability of intraoperative conditions are avoiding volatile anesthetic agents in high-risk patients, administering 100% inspired oxygen throughout the procedure, invasive hemodynamic monitoring, and maintenance of normovolemia.

A central line placement also provides a rapid route of drug administration if resuscitation becomes necessary. Orthopaedic surgeons should also consider thorough lavage of the femoral medullary canal, especially pulsatile jet lavage, removal of tissues before cementation to minimize the formation of microemboli during the procedure, and using cement restrictor to compartmentalize the bone marrow tissue and blood separately from the cement. Therefore, it can be concluded that understanding hemodynamic changes during this procedure is essential, not only for the operator but also for the anaesthesiologists.

Keywords: Bone Cement Implantation Syndrome, Cemented, Hemodynamic, Hip Arthroplasty

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INTRODUCTION

For active elderly with femoral neck fractures (FNF), total hip replacement (THR) is often the preferred mainstay of treatment. Furthermore, many surgeons prefer cemented fixation over cementless mainly because of superior outcome in terms of pain relief, walking ability, use of walking aids, activities of daily living, and because of a lower incidence of complications such as a periprosthetic fracture. However, bone cement implantation syndrome is more prevalent in cemented stems than in uncemented stems. Therefore, the importance of hemodynamic monitoring for these patients plays a critical role peri- and intraoperatively to prevent this catastrophic complication.[1,2] This literature study aims to evaluate further the hemodynamic changes in patients undergoing cemented total hip replacement surgery.

BONE CEMENT IMPLANTATION SYNDROME

In 1953, Sir John Charnley introduced the use of polymethyl-methacrylate (PMMA) bone cement. PMMA bone cement is currently used in orthopedic joint replacement surgeries, in which a combination of the polished surface, tapered stem, and PMMA bone cement provide excellent long-term results. Though it has been reported to reduce the rate of intraoperative and postoperative implant-related complications and postoperative pain, cemented hemiarthroplasty is associated with bone cement implantation syndrome (BCIS). BCIS affects the cardiopulmonary system and is a potentially fatal complication of orthopedic surgeries that utilize pressurized bone cement.[1]

BCIS is defined as a complex of sudden physiologic changes that occur within minutes of bone cement implantation. Characteristics of the syndrome are hypoxia, hypotension, sudden loss of arterial pressure, pulmonary hypertension, arrhythmias, loss of consciousness, and, ultimately, cardiac arrest. Little is known about the pathophysiology of BCIS. Still, it has been suggested that BCIS results from pulmonary embolization, complement activation, and histamine release leading to increased pulmonary vascular resistance and ventilation/perfusion disturbances.[1,3] Nolan et al., added that the changes related to BCIS were initially thought to result from the direct effects of methyl methacrylate bone cement. Still, this hypothesis has been disproved by some investigators.[4] Several animal studies have shown that methyl methacrylate can produce hypotension and hypoxemia, but the plasma levels of monomer measured intra-operatively in human studies have been too low to account for the changes in cardiopulmonary function observed. High intramedullary pressures, over 600 mmHg, are generated during the impaction of the cemented femoral stem. Highly thromboplastin intramedullary contents may be forced into the intravascular space causing aggregation of platelets in the pulmonary circulation (pulmonary embolism), accompanied by ventilation-perfusion mismatching and a decrease in arterial oxygenation. In animal studies, intramedullary pressures generated during the insertion of an uncemented femoral implant have been considerably less than those measured in the presence of cement. Consequently, uncemented implants were associated with fewer pulmonary microemboli and less cardiopulmonary dysfunction. This implies that intramedullary pressures in patients receiving uncemented total hip replacements will be lower than those receiving cemented components. Therefore through his study, he concluded that the most likely cause of changes in cardiopulmonary function during cemented total hip replacement is pulmonary embolism, with the degree of microemboli determined by the intramedullary pressure generated at the time of insertion of the prosthesis. Furthermore, insertion of cemented components during total hip replacement is known to be associated with transient decreases in arterial oxygen tension.[4]

According to Soleimanha et al., there are several theories about the cause of BCIS, which says that different components of PMMA are the leading cause of BCIS manifestations.[5] Some of these theories are: 1) The direct effect of the exothermic cement reaction; 2) Air or gas embolism caused by polymerization process; 3) Increase in intramedullary pressure resulting from the introduction of hot acrylic cement (this increase could force marrow and fat into the circulation, producing pulmonary emboli); and 4) Fat and debris from the femoral shaft emboli of the femoral canal during cement and implant insertion.[5]

The clinical features of BCIS typically occur at the time of cementation, prosthesis insertion, reduction in the joint, or deflation of a limb tourniquet. A classification system for BCIS has been proposed according to its severity as follows:[6]

- Grade 1: moderate hypoxia (SpO_2<94%) or a decrease in systolic arterial pressure (SAP) >20%.
- Grade 2: severe hypoxia (SpO_2<88%) or hypotension (decrease in SAP>40%) or unexpected loss of consciousness.
- Grade 3: cardiovascular collapse requiring cardiopulmonary resuscitation.

HEMODYNAMIC CHANGES DURING TOTAL HIP REPLACEMENT SURGERY

According to a study by Segerstad et al., more pronounced increases in pulmonary vascular resistance (PVRI) and pulmonary artery pressure, around the time of prosthesis insertion, were seen in patients receiving cemented compared to patients receiving uncemented stems.[7] However, there were no significant differences between the cemented and uncemented groups concerning MAP, SVRI, CI, SVI, CVP, heart rate, SvO2, serum hemoglobin or body temperature.[7]

A study by Soleimanha et al., also concluded that O2 saturation, pCo2, and PO2 levels did not show statistically significant changes during surgery.[5] In their study, cardiac arrhythmia occurred only in patients with a history of cardiovascular disease, while all cardiovascular changes, including an increase in heart rate and blood pressure, returned to normal levels when surgery finished. Just the acidosis remained until the end of surgery in a level of pH, which was not a life-threatening complication.[5]

Another study by Miyamoto et al., observed no difference in intraoperative blood pressure changes between cemented and cementless hemiarthroplasty.[1] Both the cemented and uncemented groups demonstrated a slight decrease in blood pressure during cementing, rasping, and insertion of the femoral component.[1] This intraoperative hypotension might be due to a reduction in stroke volume and cardiac output caused by embolic events during cementation. Nolan et al. further reported a 20% increase in mean arterial pressure after insertion of the femoral components in cemented THA.[4] Fujita et al. reported that blood pressure generally increased for 4 min on the acetabular side and for 2 min on the femoral side during cemented THA with the interface bioactive bone cement technique.[8] It is suggested that intraoperative increase of blood pressure may reflect a left ventricular response to pulmonary hypertension caused by microembolization.[1]

A study by Nolan et al., suggests that the most common response to cemented hip replacement is a 10-15% decrease in PaO_2 in association with a slight increase in mean arterial blood pressure, following

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implantation of both acetabular and femoral components.[4] Some patients do not respond at all, while in others, the decrease in PaO_2 is substantial, though temporary. The occasional severe cardiovascular collapse that has been the subject of many previous reports may be an extreme example of the same mechanism (i.e., pulmonary embolism) or maybe due to another cause, e.g., a single massive pulmonary embolus or air embolism.[4] Amongst the group of patients studied, uncemented hip replacements were associated with minimal changes in PaO_2 and MAP.[4]

MAINTAINING HAEMODYNAMIC IN CEMENTED TOTAL HIP REPLACEMENT SURGERY

Preoperative assessments of patients play an important role for the surgeon as well as the anesthetist. It involves the identification of high-risk surgical patients before operation, the evaluation and optimization of their cardiovascular reserve before surgery, and the appropriate use of this information to select the type of prosthesis, surgical procedure, and techniques to minimize the risk of cardiovascular complications.[6] Some risk factors that have been identified for BCIS in patients undergoing cemented THRs include grade III and IV ASA levels, old age, poor pre-existing physical reserve, impaired cardiopulmonary function, pre-existing pulmonary hypertension, osteoporosis, bony metastases, and concomitant hip fractures, especially pathological or intertrochanteric femoral fractures.[7,8] Though there is no clear evidence with regards to the effect of anesthetic technique on the severity of BCIS, some of the general principles that should be considered intraoperatively are the maintenance of normovolaemia to avoid cardiovascular consequences of cementing and the maintenance of high inspired oxygen concentrations. The use of high anesthetic vapor concentrations should be avoided as it is associated with a greater hemodynamic compromise with the same embolic load.[6]

A study by Memtsoudis et al., found that the induction of anesthesia and the use of a controlled hypotensive technique using a low thoracic epidural was accompanied by a reduction (although not significant) in pulmonary arterial pressures and vascular resistance compared with baseline, while cardiac output was maintained.[9] This approach may be viewed as beneficial when dealing with the embolic phenomenon to the lung. Animal studies have shown that the use of a thoracic epidural block improves hemodynamic by reducing mean pulmonary pressure and raising cardiac index in the setting of pulmonary embolism, a situation with similar hemodynamic consequences observed during intramedullary debris and cement embolization of the lung.[9] The fact that thoracic but not lumbar epidural placement of the catheter has been associated with this beneficial effect seems to point to the role of a sympathetic blockade in this process.[9]

Furthermore, cemented bilateral hybrid THA is proven to be associated with increases in pulmonary artery pressures and vascular resistance, particularly after completion of the second side. As keeping patient safety a priority, the performance of bilateral procedures should be cautiously considered and perhaps staged in patients with diseases, suggesting decreased pulmonary reserve and increased right ventricular afterload, that is, pre-existing pulmonary hypertension.[9] On the other hand, for patients with significant cardiovascular and respiratory disease, the risk of significant immediate complications may be lower after insertion of uncemented components.[4]

Also, the use of intraoperative CO monitoring has been recommended in patients with one or more risk factors for BCIS. Some examples are the use of a semi-invasive transoesophageal Doppler monitor or an invasive CO monitor (pulmonary artery flotation catheter).[6-8] Intraoperative transoesophageal Doppler is beneficial in improving fluid management, early detection of cardiovascular changes around the time of cementing, and reduce postoperative cardiopulmonary complications in hip surgery. A transoesophageal Doppler study involving patients undergoing hip arthroplasty demonstrated the superiority in detecting cardiovascular changes during cementing compared with standard hemodynamic monitoring, recommending its use in high-risk patients. Pulmonary artery flotation catheter and transoesophageal echocardiography should also be considered in high-risk patients. But their use is limited by their availability and expertise required to use them.[6]

Some anesthetic measures that can be done to keep the stability of intraoperative conditions are avoiding volatile anesthetic agents in high-risk patients, administering 100% inspired oxygen throughout the procedure, invasive hemodynamic monitoring, and maintenance of normovolemia.[7,8] A central line placement also provides a rapid route of drug administration if resuscitation becomes necessary. Orthopedic measures include thorough lavage of the femoral medullary canal, especially pulsatile jet lavage; removal of tissues before cementation to minimize the formation of microemboli during the procedure; and using cement restrictor to compartmentalize the bone marrow tissue and blood separately from the cement.[9,10] The latter minimizes the piston-like effect of pressurized cement on these tissues. Whenever BCIS happens, the cornerstone of therapy lies in providing prompt and effective supportive care and monitoring in the intensive care unit with the administration of 100% oxygen, central venous catheter placement for rapid delivery of inotropes, and invasive hemodynamic monitoring. Hypotension should be treated on the lines of acute right ventricle (RV) failure.[9,10] Fluid resuscitation to maintain the RV preload and inotropes to support ventricular contractility is recommended. Care should be taken to avoid overzealous fluid infusions, as it may cause an increased leftward shift of interventricular septum, which would lead to a further drop in left ventricular output. Vasopressors phenylephrine and noradrenaline cause peripheral vasoconstriction and therefore increase aortic blood pressure, which in turn supports coronary artery blood flow and improves myocardial perfusion and contractility.[10]

CONCLUSION

Perioperative hemodynamic monitoring thorough preoperative assessment, and careful choosing of surgical technique play essential roles in the application of cemented hip arthroplasty, as well as to prevent possible related complications.

CONFLICT OF INTEREST

There is no competing interest regarding manuscript.

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AUTHOR CONTRIBUTION

The author himself is responsible for the literature study from data collection, narrative synthesis, until reporting the results through publication.

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