Review Article

Anesthesia for bone replacement surgery

Sunil Singh, Shri Prakash Singh, Jitendra K Agarwal

Department of Anaesthesiology, Dr. BL Kapur Memorial Hospital, New Delhi, India

Abstract

Advances in clinical medicine, improved understanding of pathophysiology, and the extensive application of medical technology have projected hitherto high risk and poor outcome surgical procedures into the category of routine and relatively good outcome surgeries. Bone replacement surgery is one amongst these and is wrought with a multitude of perioperative complexities. An understanding of these goes a long way in assisting in the final outcome for the patient. Here we present a review of the literature covering various issues involved during the different stages of the perioperative period.

Key words: Antifibrinolytic therapy, bone replacement surgery, DVT prophylaxis, hypothermia, postoperative analgesia, pulmonary embolism

Introduction

Advances in the understanding of various pathophysiological phenomenon and developments in biomedical engineering have influenced surgical techniques. Bone replacement surgical patients pose multifaceted challenges to the anesthesiologists. These patients range from the elderly with reduced physiological reserves and multiple comorbidities, through, to young, trauma patient whose associated injuries have the potential to significantly influence the anesthetic management.

Bone replacement surgical procedure fall into one of the following types:

- Hemiarthroplasty;
- Total joint replacement;
- Segmental or total bone replacement;
- Revision bone replacement surgery.

The surgery involves filling the bone defect with polymethylmethacrylate or an endoprosthesis or a combination of both.

Address for correspondence: Dr. Sunil Singh,
Department of Anesthesiology, Rockland Hospital, HAF, Phase – 1, Pocket – B, Sector – 12, Dwarka, New Delhi - 110 075, India.
E-mail: drsunilanaes@gmail.com

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The problem

Like all surgical procedures, bone replacement is thrombogenic and ischemogenic. The surgery often mandates a long duration of anesthesia in a cooler operating room, usually on an elderly patient with associated comorbidities. It is associated with significant operative blood loss in a physiologically deconditioned patient. Coupled with these factors is the real threat of cement-bone marrow embolization. This completes the recipe for perioperative cardiopulmonary complications in this subset of surgical patients. Thus predisposed, the patients are vulnerable to develop hemodynamic dysfunction from electromechanical aberrations of the cardiovascular system. The mechanical functional changes commonly affect the right ventricle and are usually small and clinically insignificant. The electrical derangement usually manifest due to acid–base imbalance.

Risk factors

Surgical procedures are classified as high, intermediate, or low risk.[1] Orthopedic surgical procedures are classified as having intermediate risk for the development of adverse cardiac events. Bone replacement patients are at higher risk for adverse cardiorespiratory events due to[2,3]

- Advanced age of the patient (>75 years);
- Male gender;
- Reduced physiological reserves and blunted compensatory mechanisms;
- Associated comorbidities;
- Physical deconditioning;
- Surgical stress and problems associated with the procedure.

Associated comorbidities increase the risk of perioperative complications. The increase ranges from 1.28 times with lung disease to 2.32 times for fluid and electrolyte abnormalities. Congestive heart failure and pulmonary hypertension increase the patient's risk for complications or death by 5.5 and 4 times, respectively. Patients with increased pulmonary pressures or right heart dysfunction, including patients with sleep apnea and those with a history of pulmonary embolism, should be considered at high risk.[2] Uncontrolled diabetes is associated with a higher risk of surgical and systemic complications resulting in a higher risk for mortality, and increased duration of hospital stay following lower extremity total joint arthroplasty.[3]

Preoperative risk assessment

Clinical risk assessment attempts to identify patients at low, intermediate, and high risks for adverse cardiac outcomes. This risk stratification must take into cognizance general physical condition of the patient, associated comorbidities, and impact of the physiological derangements consequent to the nature and extent of surgery. The ACC/AHA Guidelines (2007) on perioperative cardiovascular risk assessment outline the best practices in cardiac risk stratification for noncardiac surgery. The crux of the recommendation is that "preoperative intervention for a cardiac condition is rarely needed simply to reduce the risk of surgery unless such intervention is indicated separate from the preoperative context."[4]

Absolute contraindications to proceeding with elective bone replacement procedures include recent infarction (less than 3 months), unstable angina, decompensated congestive cardiac failure (CCF), and symptomatic aortic and mitral valve stenosis. Relative contraindications include mild CCF, class III angina pectoris, symptomatic arrhythmias viz. ventricular tachyarrhythmia, complete heart block, and supraventricular arrhythmias with poorly controlled ventricular response.

The incidence of life-threatening complications

The mortality after hip and knee arthroplasty surgery ranges from 0.4% to 4.6%, depending on primary or revision arthroplasty.[5-7] The commonest major risk factor for perioperative mortality is advanced age and the most frequent perioperative complications involves cardiac function. The most common complications after total hip arthroplasty (THA) and total knee arthroplasty (TKA) are[7-9] adverse cardiac events, thrombosis and pulmonary embolism, pneumonia and respiratory failure, sepsis, and stroke.

Anesthesia technique

Recent studies[10-13] have compared regional anesthesia with general anesthesia for adverse cardiac events. O'Hara *et al.*,[10] in their study, were unable to demonstrate any significant difference in the cardiac complication rate. However, Rodgers *et al.*,[11] Urwin *et al.*,[12] and Luger *et al.*[13] have demonstrated a lower incidence of myocardial infarction in patients who received neuraxial anesthesia.

The choice of anesthetic technique has implications for the intraoperative course and postoperative outcome. A fine balance is to be attained between establishing optimal surgical conditions and maintaining physiological stability. Continuation of good analgesia postoperatively is crucial to achieving physiotherapeutic milestones. All these, in turn, influence the overall functional outcome and the ultimate result of surgery.

The choice of anesthesia technique is governed by the physical status of the patient and the extent and region of surgery. As determined by these characteristics, the surgical procedure can be done under

- General anesthesia – balanced anesthesia or total intravenous anesthesia (TIVA) with controlled ventilation using a supra – glottic device or endotracheal tube;
- Neuraxial or nerve plexus block with or without sedation.

Patients must be monitored according to the minimum monitoring standards advocated by the Indian Society of Anaesthesiologists for adequacy of oxygenation, ventilation, and circulation, both clinically and with appropriate monitors.[14] Invasive hemodynamic monitoring, viz. central venous pressure (CVP), intra-arterial pressure (IAP), and cardiac output (CO), must be done if indicated for monitoring and guiding fluid management, monitoring and guiding pharmacological interventions, estimating adequacy of tissue perfusion and oxygenation, and frequent blood sampling.

Crystalloids as well as colloids are commonly used to substitute fluid derangements in surgical procedures. Salt solutions freely cross capillary membranes and equilibrate within the extracellular compartment. Within 20–30 min, 75–80% of the infused volume lodges in the interstitial fluid space. Such a therapy includes a risk of tissue edema. The greater capacity of colloids to remain within the intravascular space results in a more efficient expansion of the intravascular volume, better hemodynamic stability, and better coagulation profile, microvascular blood flow, and oxygen transport. Resuscitation with either alone is inferior to a combination transfusion regimen. Colloids are preferred *in situ*ations where the main requirement is to increase intravascular volume, while crystalloids are needed for correction of extravascular fluid derangements. The comparative risks of the various colloids are given in the Table 1.

Table 1: Comparative risks of commonly available colloids

Colloid	Risks		
	Anaphylactoid reaction	Renal dysfunction	Hemostasis
Dextran	High	High	High
Gelatin	High	Unclear	High
Starch	Low	Mild	Mild

One liter of 6% solution of hydroxy-ethyl starch (HES) reduces coagulation factor VIII level by 50% and will prolong activated partial thromboplastin time (aPTT). These are more manifest especially when the dose limit provided by the manufacturer is exceeded; however, no such effects have been reported to date for modern tetrastarches.[15] A Cochrane review did not find evidence to show that one colloid solution is more effective or safer than any other, although the confidence intervals are wide and do not exclude clinically significant differences between colloids.[16]

Oxygenated polyethylene glycol-modified hemoglobin, MP4OX, an oxygen therapeutic agent with potential applications in clinical settings where targeted delivery of oxygen to ischemic tissues is required, has been used successfully in arthoplasy. It is not meant to mimic or to replace the use of transfused blood or red blood cells and is designed to improve the perfusion and oxygenation. Its role in reducing the incidence of hypotensive episodes in surgical patients is being studied.[17,18]

Mason *et al.*[19] in their meta-analysis found no effect of anesthesia type in developing postoperative delirium, whereas general anesthesia was associated with a marginal increase in postoperative cognitive dysfunction. The drug used for the conduct of general anesthesia, i.e., induction agent, opiate/NSAID, muscle relaxant, and inhalational agent should be determined by the patient's organ systems performance, hemodynamic status, and respiratory function. Anesthesia has not been conclusively proven to be associated with postoperative cognitive dysfunction and delirium.

Regional anesthesia, where feasible, is probably the technique of choice because it[13,20] reduces blood loss and blood component transfusion requirements, improves cement bonding, decreases surgical time, decreases the incidence of DVT and pulmonary emboli, is associated with lesser acute postoperative confusion, reduces chances of myocardial infarction, and is associated with lesser incidence of pneumonia.

The amino-amide agents are preferred over the ester-amino agents for establishing regional blocks for bone replacement surgery because of their longer duration of action and lower incidence of toxicity. The common drugs used are 0.5% bupivacaine and 0.75% ropivacaine. The recommended dose for epidural anesthesia is 1.0–2.0 ml/dermatome to be blocked. For postoperative analgesia, the drug concentrations are reduced to 0.125% for bupivacaine and 0.2% for ropivacaine. Factors such as age and height of the patient must be taken into consideration when administering a neuraxial block. Opioid as an adjuvant to the local anesthetic reduces the amount of the local anesthetic without compromising on the quality of block with the additional advantage of prolonging the duration of analgesia.

The preferred concentration for nerve plexus block is a low concentration and large volume of local anesthetic delivered under ultrasound guidance with a nerve stimulator. Alpha2 adrenergic agonists are popular adjuvants in nerve plexus and neuraxial blocks. Contraindications to the use of alpha2 adrenergic agonists in these blocks include hypersensitivity, disorders of cardiac pacemaker and conduction, hypertensive patients on diuretics, vasodilators, and negative chronotropic agents viz. calcium channel blockers, β blockers, and pregnancy and lactation.

The safe conduct of regional anesthesia involves knowledge of the patient, anesthetic agent, and the surgical risk factors. Regional anesthesia is associated with perioperative neural injuries. Although rare, an uptrend in their occurrence has been documented.[21] The risk factors include trauma during needle or catheter placement, infection, and choice of local anesthetic. Nerve injury due to pressure from improper patient positioning, tightly applied casts or surgical dressings, and surgical trauma are commonly attributed to the regional anesthesia. Pre-existing neurologic dysfunction may also contribute to this phenomenon. Early diagnosis and prompt treatment of reversible etiologies are critical to optimizing neurological outcome.

Sedation is often desirable as it improves the patient's comfort level. Target-controlled infusion (TCI) of propofol, 0.5–2.0 mcg/ml, gives a smoother and more titratable sedation. Intermittent aliquots of midazolam may be used, but it can cause intraoperative disorientation and confusion.

Intraoperative oxygen therapy is mandatory during surgery under regional/neuraxial anesthesia with mild to moderate sedation. The aim of such a therapy is to administer oxygen at concentrations greater than the ambient air with the intent of preventing hypoxia. Rozario *et al.* found that these patients are 98% less likely to experience desaturation.[22] Catterell *et al.* found that a flow rate of 5 L/min, through the medium concentration (MC) mask, is adequate to provide a mean fractional inspired oxygen concentration (FiO_2) inside the mask of >50%, with zero carbon dioxide (CO_2) concentration inside the MC mask between breaths.[23]

Intraoperative issues

Patient position

Patients positioned laterally may become restless and uncomfortable because of pain arising from the dependent shoulder. Use of an NSAID or an opioid is a suitable option. The lateral position also entails a risk of excessive lateral neck flexion.

Hypothermia

Orthopedic theaters, in particular bone replacement theatres, are cooler than other theaters (18–20ºC and >55% humidity), with high velocity airflow. The low ambient temperature coupled with impaired temperature regulatory mechanism in the elderly leads to rapid patient cooling. Hypothermia increases the incidence of morbid myocardial outcomes, reduces resistance to surgical wound infections, and prolongs both postanesthetic recovery and hospitalization. It causes coagulopathy due to inhibition of platelet function resulting in increased perioperative blood loss.[24,22] Surgical site infection in this subset of patient can jeopardize the treatment plan. Patient warming devices should be used intraoperatively to prevent hypothermia. Opponents of the patient warming devices contend that they are potential sources of nosocomial infections. Moretti *et al.* found that the use of a forced warm air convective system does not pose a real risk for nosocomial infections.[25]

Blood loss

The average blood loss in primary THA ranges from 3.2 ± 1.3 units corresponding to a hemoglobin loss of 4.07 ± 1.74, with 87% losing 5.8 g. The loss in primary knee arthroplasty ranges between 1000 and 1500 ml and averages 3.85 ± 1.4 g of hemoglobin with 87% losing <5.25 g of hemoglobin. The loss is greater from the second knee when bilateral knee arthroplasty is performed and carries a higher incidence of coagulopathy. These values double in revision surgery.[22,26] Preoperative hematocrit, blood pressure, blood volume, weight, and age of the patient are significant indicators of perioperative blood transfusion. Patients with a preoperative hemoglobin of <10 g/dl have a 90% chance of needing a transfusion, which reduces to 15–25% if the hemoglobin is >13.5 g/dl.[22]

Careful fluid balance is essential because compensatory mechanisms for hypovolemia are poor in the elderly and those with associated comorbidities. Hemtocrit is a good tool to guide blood transfusion requirements, provided normovolaemia has been maintained.

Predonation of blood using acute normovolaemic hemodilution is useful if the patient has an adequate starting hematocrit. An adjunct to preoperative autologus blood donation is perioperative blood salvage. It can salvage up to 60% of intraoperative blood loss.[22] The cell saver cannot be used once cement is in use. The use of the cell saver is contraindicated in patients in whom bone replacement is for metastatic disease or infection.

Antifibrinolytic therapy

A single intravenous dose of tranexamic acid (10 mg/kg) given prior to the commencement of surgery is effective in minimizing blood loss and reducing the need for allogenic blood transfusion.[27] Tranexamic acid was found to reduce intraoperative blood loss by 104 ml, postoperative blood loss by 172 ml, and total blood loss by 289 ml in patients undergoing unilateral THA.[28] The CRASH-2 trial recommends administration of tranexamic acid 1.0 g intravenously over10 min, followed by a continuous infusion of 1.0 g over 8 h.[29]

Cement reactions

Showers of microemboli of blood, fat, and or, platelets are forced into the circulation by high intramedullary pressure generated during cement packing and prosthesis insertion.[30,31] The embolic event can be observed by transesophageal echocardiography and correlates with the consequent hemodynamic changes - drop in systemic blood pressure, rise in pulmonary artery (PA) pressure and fall in right ventricular ejection fraction (RVEF). Hypoxemia is indicated by the concomitant drop in oxygen saturation. The ability of patients to tolerate this cardiopulmonary insult depends on the baseline pulmonary function and the quantity of embolic debris delivered to the pulmonary vasculature. Patients with good pulmonary function can tolerate this embolic load. While patients with poor pulmonary reserve are unable to withstand this insult and are at risk for hypoxia, cardiopulmonary dysfunction, and possibly death.

These are more often seen in bilateral arthroplasties and in under-resuscitated patients. It is less common in knee vis-à-vis hip arthroplasty. It is, therefore, vital to ensure that these patients are not hypovolemic before cementing. FiO_2 concentration may need to be increased to maintain adequate oxygen saturation.

Venous embolization

The 8th ACCP guidelines on thromboprophylaxis rates hip and knee arthroplasty as high risk for DVT with a 40–60% chance for development of deep vein thrombosis (DVT) without prophylaxis.[32] The maximum risk of thrombogenesis occurs during, rather than after, arthroplasty. Conventional cementing techniques result in embolization of tissue thromboplastin into the veins leading to activation of the clotting cascade and thrombogenesis. Using of the bone-vacuum technique has

been shown to reduce the quantity of embolization.[33] Using an external pneumatic compression device in conjunction with anticoagulants significantly reduces venous thrombosis.[32] The best thromboprophylactic agent in terms of both efficacy and safety is warfarin.[34]

Tourniquet

Tourniquet reduces intraoperative blood loss and operative time by providing a bloodless operative field. Simultaneously, tourniquet inflation increases the systemic vascular resistance and may result in left ventricular failure in predisposed patients. Release of the tourniquet exposes the circulation to high acidosis, procoagulants, and cytokines from the distal portion of the limb, which may be deleterious to an already compromised myocardium. A systematic review and meta-analysis[35] found significantly greater intraoperative blood loss in nontourniquet compared to tourniquet assisted surgery, with no significant difference in total blood loss or transfusion rate. There was, however, a trend for greater complications in tourniquet compared to nontourniquet patients.

Tourniquets are usually inflated to a pressure 100 mmHg above the patient's systolic blood pressure for 1–3 h. Nerve injury after extended tourniquet inflation (>120 min) has been attributed to the combined effects of ischemia and mechanical trauma. Peroneal nerve palsy is a recognized complication of TKA (incidence of 0.3%–10%). It may be caused by a combination of tourniquet ischemia and surgical traction.[36]

Pain related only to tourniquet inflation may occur after about 60 min, despite the presence of adequate regional anesthesia. The mechanism postulated for this pain is the unblocking of unmyelinated "C" fibers during recession of a neuraxial block. The addition of narcotics to spinal or epidural anesthesia may ameliorate this tourniquet pain.

Revision arthroplasty

With the increasing population of the active elderly people, more patients are returning for revision of their earlier replacements. Revision arthroplasties have added complications associated with prolonged duration of surgery and excessive blood loss besides the other problems associated with bone replacement surgery.

Postoperative management

The immediate postoperative management needs to be done in the postanesthesia care unit (PACU). The PACU is expected to hold the patients for a limited period of time (usually 2 h). However, patients with moderate to high surgical risk, known cardiac or respiratory compromise, and those who have intraoperative complications, need a prolonged period of observation. These patients should be observed in an intensive care unit (ICU). This ensures close physical observation of the patient and monitoring of physiological parameters with early active management of complications.

Oxygen (O_2) is categorized as a drug and hence it must receive a proper prescription. Its prescription therefore must mention specific delivery device, desired FiO_2, duration, monitoring efficacy of therapy, and when to end. The delivery device must be selected, based on the clinical condition of the patient and the amount of O_2 needed. High flow systems are preferred for patients who need precise control of FiO_2. Low flow masks are appropriate for patients who need supplemental O_2, but do not require precise control of FiO_2. Adequacy of therapy is assessed by frequent clinical assessment and SpO_2 estimation in all patients receiving O_2 therapy. Periodic estimation of blood gases may be required to screen for respiratory acidosis. FiO_2 is titrated to achieve therapeutic goals while minimizing the risk of complications. A SpO_2 of 90% to 95%, corresponding to a $Pao_2 \approx 60–80$ mmHg, is an appropriate target for most patients.[37]

Disturbances of oxygenation in a patient during the early postoperative period occur frequently. Hypoxia of pulmonary origin arises mainly due to ventilation perfusion disturbances or increases in intrapulmonary shunt. Hypoxia from nonrespiratory origin is mainly caused by a drop in CO or by an increase in the tissue oxygen consumption. Bone replacement surgery is associated with pulmonary embolism. Pre-emptive O_2 therapy is prescribed to reduce the manifestations and consequences of tissue hypoxia by increasing the FiO_2.

Effective analgesia must be provided by a continuous epidural infusion with regular enteral or parenteral NSAIDs/paracetamol, or intravenous opioids utilizing the PCA pump. Close control of fluid balance is desirable. It is a major factor which influences CO by determining the preload. Central venous pressure and hourly urine output measurements are commonly employed methods to determine fluid therapy.

Coagulopathies need to be treated promptly. The threshold to transfuse red cells depends, also on the presence of comorbidities, especially ischemic heart disease. DVT is common after bone replacement surgery. Venous thrombosis is more common following TKA than THA. DVT following TKA are generally distal calf thromboses with a low risk of pulmonary embolism. THA surgery causes extremes of movement, at the hip, resulting in kinking of vessels and damage to the endothelium, resulting in stagnation of blood with activation of the coagulation cascade - resultant

thromboses tending to be in the proximal veins with a higher risk of embolization.

Despite pharmacological thromboprophylaxis, patients undergoing bone replacement surgery remain susceptible for venous thromboembolic events even after surgery. Patients with high score on the Charlson comorbidity index, history of cardiovascular disease and previous venous thromboembolism have an increased risk for postoperative venous thromboembolism compared with patients without these conditions.[38]

The use of a regional technique, early initiation of low-molecular-weight heparin (LMWH) (0.5–1.0 mg/kg within 6 h of surgery), graduated compression stockings, or pneumatic compression devices decreases the risk of DVT.[34] The optimal duration of therapy is unknown. LMWH is continued for at least 10 days routinely in patients not considered high risk. Extended prophylaxis up to 35 days is appropriate in patients with evidence of DVT or at high risk.[32,39] Warfarin is usually employed for long-term treatment of DVT, with a target international normalized ratio (INR) of 2.5. Fondaparinux, a synthetic pentasaccharide, is a suitable alternative to LMWH. It is a selective inhibitor of factor Xa with a prolonged half-life of 18 h. A predictable anticoagulant response occurs with a once daily dose.[40]

The risk of an epidural hematoma is significantly increased with the use of LMWH.[41,42] The American Society of Regional Anesthesia (ASRA)[41] recommends that an interval of 12 h should be observed after administration of the usual dose of LMWH and placement of a neuraxial block. In patients receiving larger doses of LMWH (enoxaparin 1 mg/kg every 12 h), the delay should be extended to 24 h. Epidural catheter removal should occur at least 8–12 h after the last LMWH administration, or 1–2 h before the next administration of LMWH. In patients receiving warfarin, the prothrombin time and INR should be checked before neuraxial anesthesia, and an epidural catheter should not be removed if the INR is greater than 1.5. In a retrospective review of more than 12,000 TKA's who received warfarin postoperatively, and an epidural catheter was maintained for analgesia, there were no reported epidural hematomas despite patients having an INR greater than 1.5.[43]

Special Concerns

Fat embolism syndrome

Fat Embolism and *Fat Embolism Syndrome* (FES) are not synonymous. Fat embolism syndrome (FES) is a physiologic response to fat within the systemic circulation. The embolization of fat can be detected in almost all patients who undergo cemented arthroplasty,[31] but the incidence of FES is less than 1%.[44]

The clinical manifestations of FES include respiratory, neurologic, hematologic, and cutaneous signs and symptoms. The presentation of FES can be gradual, developing over 12–72 h, or fulminant leading to acute respiratory distress and cardiac arrest. Respiratory signs are common in FES. Approximately 75% of patients present with mild hypoxemia, but less than 10% progress to acute respiratory distress syndrome. The neurologic manifestations of FES range from drowsiness and confusion to sensory obtundation and coma.

The fat emboli lodged in the microvasculature of the lung and other end organs metabolize to free fatty acids, which triggers a systemic inflammatory response. This inflammatory response involves the invasion of inflammatory cells and release of cytokines, which induce pulmonary endothelial damage and acute respiratory distress syndrome.[45]

The treatment of FES is supportive with early resuscitation and stabilization to minimize the stress response to hypoxemia, hypotension, and diminished end-organ perfusion. Patients at risk for developing FES should be monitored with pulse oximetry. In most patients the symptoms resolve within 3–7 days. Corticosteroids have been studied extensively in the management of FES, with many investigators reporting beneficial effects, while other reports contradict these results.[46]

Bilateral total knee arthroplasty

Bilateral TKA is an oft performed procedure in most centers. It is, hence, extremely crucial to understand when to exercise restraint during bilateral TKA. Two recent reports suggest that bilateral TKA can be performed without major complications.[47,48] Urban and associates[47] reported that with regional anesthesia and aggressive clinical management, which included 24-h postoperative monitoring in an ICU, bilateral TKA patients had a major complication rate similar to matched controlled unilateral TKA patients. Loner *et al.*[48] found that bilateral TKA patients exhibited a significantly higher incidence of FES and cardiac arrhythmias vis-a-vis unilateral TKA patients did. Based on these the following restrictions could be surmised as follows:

- Age > 75 years;
- ASA class III;
- Active ischemic heart disease (stress test +ve for inducible ischemia);
- Poor ventricular function (left ventricular ejection fraction < 40%);
- Oxygen-dependent pulmonary disease.

Conclusion

Anesthetic management for bone replacement surgery is daunting. It requires an understanding of the surgical procedure with its incident physiological effects. A fine balance has to be achieved between providing optimal surgical conditions and achieving best physiological activity during the perioperative period. Close patient monitoring, starting from the intraoperative period and its continuation into the postoperative period, with the aim of early identification of complications and prompt aggressive initiation of therapy is paramount. All this, coupled with good postoperative analgesia and early adequate thromboprophylaxis will reduce morbidity and mortality, and help in early initiation and accomplishment of physiotherapeutic targets so that the ultimate goal of the procedure is realized.

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