CHAPTER 33

Bone Cement

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INTRODUCTION

When total hip arthroplasty was initially introduced into practice, it had the highest mortality rate of any noncardiac surgery. A considerable portion of the risk associated with this surgery has been attributed to methylmethacrylate (MMA) cement. Although the use of MMA for medical procedures—such as prosthetic middle ear ossicles, encapsulation of cerebral aneurysms, and prosthetic testicles—is long-standing, the large volume of MMA used and the fact that the curing process occurs primarily in vivo made hip arthroplasty a unique setting for this product. As surgeons and anesthesiologists gained experience with this method and learned how to anticipate the difficulties associated with it, the mortality rate of hip arthroplasty improved greatly.

Additionally, improved prosthetic joints make MMA necessary only in those patients in whom it is expected that the interface between the patient (bone) and the prosthesis will not tolerate the external stresses placed on them—for example, patients older than 70 years. However, even with its less frequent use, the implications of MMA use in patients demand that anesthesiologists have a full and complete understanding of its physiologic ramifications.

Another important aspect of bone cementing that requires attention is the setting in which cementing is done. Vertebroplasty and other uses of MMA not related to arthroplasty exhibit some of the physiologic challenges of MMA use. However, in looking at the effects of bone cement in the most significant orthopaedic uses, the effects of long bone reaming and prosthesis insertion cannot be overlooked. The rest of this chapter is therefore primarily devoted to the role of MMA in hip arthroplasty procedures in conjunction with the placement of prosthetic devices.

CHEMICAL COMPOUND

MMA (more correctly polymethylmethacrylate), is a vinyl polymer formed by free-radical polymerization from the monomer MMA. This polymer is a strong, lightweight material, commonly seen as Plexiglas at hockey games or as large windows at aquariums. It is also utilized in acrylic latex paints and as a viscosity-reducing agent in oils and fluids. The strength and lightness of MMA and its ability to be shaped and molded also make it an ideal space-occupying, load-transferring material for distributing the forces of the various prosthetic components used in arthroplasty procedures.
more recently in vertebroplasty procedures, has increased the durability of these repairs, the use of this product has anesthetic implications. These implications are most evident in hip arthroplasty procedures, particularly because of the large amount of cement used in these cases.

The cement is supplied as two components, one a liquid and one a powder. The liquid contains MMA monomer with an accelerator (dimethylparatoluidine) included. The liquid also contains a retardant to prevent monomer polymerization during storage. The powdered polymer contains poly-MMA particles, a radiopaque component (barium sulfate or zirconium dioxide), and benzyl peroxide to initiate the reaction. When mixed, the dimethylparatoluidine is activated by the benzyl peroxide in the powder. Dimethylparatoluidine is an aromatic tertiary amine that causes the benzyl peroxide to decompose rapidly, producing large amounts of free radicals, and catalyzes the formation of the polymer. The curing process therefore occurs once all the products are mixed. Other additives may also be incorporated into the cement, including heat-stable antibiotics (gentamicin, tobramycin, erythromycin, vancomycin, or cephalosporin) or colorants, such as methylene blue or chlorophyll, to allow differentiation from bone during revision procedures. The powder and liquid components are mixed just before implantation, causing the liquid monomer to polymerize and form the final cement. To reduce the porosity of the cement, it is often mixed with a 500-mmHg vacuum or with the assistance of a centrifuge. Reducing the porosity improves the fatigue properties of the cement.

The exothermic polymerization reaction, known as curing, occurs over several minutes and is divided into time periods. The “dough” time begins at mixing of the liquid and powder and typically continues for 2 to 3 min, until the cement will no longer stick to unpowdered surgical gloves. The “working” time immediately follows dough time and continues for about 5 to 8 min, until the cement is too stiff to manipulate. These two times together make up the “setting” time of the cement. A decrease in room temperature increases the setting time by about 5 percent per degree centigrade. It is during the setting time that the cement is placed into close proximity to the patient’s cancellous bone. Since the cement finishes curing in vivo in arthroplasty procedures, a unique physiologic response is attributed to it.

PHYSIOLOGIC AND PHARMACOLOGIC EFFECTS OF METHYLMETHACRYLATE

The myriad of physiologic changes that are often attributed to MMA include both immediate and long-term effects. These effects include hypotension, pulmonary embolus, hemorrhage, hemotoma, variations in cardiac conduction, myocardial infarction, cerebrovascular accident, deep and superficial wound infections, and thrombophlebitis in the period surrounding the placement of the bone cement. After placement of the bone cement, trochanteric separation, loosening or displacement of the prosthesis, heterotopic new bone formation, and trochanteric bursitis have been reported.

Of primary concern to the anesthesiologist are the immediate effects after the introduction of MMA into the body. The physiologic changes seen after implantation are variable in magnitude but qualitatively fairly consistent. These changes principally involve the cardiovascular and pulmonary systems, either directly or indirectly.

The main pharmacologic effect of the MMA monomer is as a direct vasodilator. This effect is typically seen in the first minute after application and can continue for as long as 10 min afterward. The amount of change in blood pressure is directly proportional to the patient’s existing blood pressure, age, and blood loss. Conversely, euvoletic patients and those under epidural or spinal anesthesia exhibit less of a decrease in blood pressure, especially if blood pressure is not increased at the time of MMA insertion.

Another effect of the placement of cemented prostheses is a decrease of the patient’s PaO2. This is seen at its greatest magnitude in hip arthroplasty procedures with the insertion of the femoral prosthesis. It is thought that the drop in arterial oxygenation is primarily due to pulmonary embolism of MMA as well as fat, clots, air, and bone fragments. This drop can occur within the first minute after insertion of the prosthesis and continue for several minutes afterward. A decrease of 20 to 80 mmHg is typically seen. As expected, the decreasing arterial oxygenation causes an increase in pulmonary artery pressures.

Also seen with insertion of the prosthesis is a decrease in the total compliance of the lungs. This may occur as a result of airway constriction. Because of decreased compliance, end-inspiratory pressures increase. The increase in pulmonary end-inspiratory pressure may cause the increase in anatomic and alveolar dead space that is seen with prosthesis insertion.

In addition, it is important to recognize that when the net effects of MMA cement and emboli are combined, namely hypotension and pulmonary hypertension, reversal of the normal left-to-right atrial pressure gradient can occur. When this occurs in the presence of circulating emboli, especially if positive-pressure ventilation is being used, the patient is at risk for paradoxical embolic events.

Another interesting result of the use of MMA is the presence of specific tissue inflammatory mediators, particularly prostaglandin E2, interleukin-1, and tumor necrosis factor, which are seen at the cement-bone interface. In fact, a macrophage–giant cell reaction that is similar to a type IV hypersensitivity reaction is often found at the interface. The most common sequelae of this reaction appear to be
early loosening of the prosthetic components (aseptic loosening). Of interest to the anesthesiologist, patients with this complication of arthroplasty may actually be manifesting a sign of allergy to the bone cement. There have been reports of allergic dermatitis to bone cement, particularly to the accelerator dimethylparatoluidine, in orthopaedic surgeons, dentists, and other operating-room personnel who have come into contact with the substance.

Other important issues to be aware of concern local tissue effects of the cement. Because of the heat produced by the exothermic polymerization reaction, local coagulation products may be ineffective.

**CEMENT IMPLANTATION SYNDROME**

The most serious effect of the placement of MMA bone cement is the phenomenon known as cement implantation syndrome. This syndrome is a triad of systemic hypotension, pulmonary hypertension, and hypoxia at the time when a joint prosthesis is inserted. There have been many explanations for the syndrome, but it appears that a combination of MMA effects on vascular structures and pulmonary microembolism of fat and thromboplastic products or air are the culprits. It is essential that the anesthesiologist should understand this syndrome, since a vast number of case reports provide evidence of serious adverse events, including death, in patients with this syndrome.

As indicated, cement implantation syndrome is multifactorial, MMA being one of the main components. This cement is unusual among implanted materials in that it is created by a reaction in the operating room and in the patient. The significance of this reaction lies predominantly in the release of free, un polymerized MMA monomer. This monomer is volatile, as people present in an operating room during its use well know. It can therefore easily be absorbed into the circulation, where it is either metabolized or excreted directly through the lungs. Intravascular MMA acts as a direct vasodilator, which partially explains the hypertensive episodes commonly seen between 1 and 10 min after its use.

During hip arthroplasty, MMA can enter the circulation and cause its potentially deleterious effects in two different ways. Just before the placement of the femoral prosthesis, the freshly reamed femoral shaft is filled with incompletely cured MMA. At this point, the volatile substance (monomer) can be absorbed directly into the circulation. Second, when the prosthesis is actually placed into the femoral canal, the bone cement, as well as air and fat, can be forced into the venous sinuses of the femur and thus cause venous emboli. Evidence supports the theory that the most important pathogenic factor for the development of embolism during arthroplasty is an increase in intramedullary pressure due to mechanical compression of the femoral canal during insertion of a prosthesis. The heat generated by the implanted material during polymerization further increases the air pressure in the shaft, and air can then readily enter the bloodstream. Since the surgical approach determines much of the embolic risk of the procedure, it is of paramount importance that the anesthesiologist be involved in, or at least aware of, the chosen surgical plan. Surgical precautions are necessary to avoid or minimize cement implantation syndrome. The avoidance of excessive cement pressurization by venting of the shaft, utilization of a low-viscosity cement, meticulous high-pressure canal lavage, and the use of a venting hole are effective techniques to minimize intramedullary canal pressures and thus decrease emboli.

Despite all possible precautions, most practitioners caring for arthroplasty patients will undoubtedly observe the physiologic and pharmacologic effects of the implantation of bone cement. These effects vary in magnitude but are qualitatively consistent.

Pulmonary fat embolism has been strongly implicated as a main cause for the physiologic effects, and echocardiography studies have clearly shown emboli containing fat to be present during arthroplasty procedures. There are two theories to explain how fat emboli are formed. The first suggests that fat deposits in tissue and bone marrow are released into the circulation as a result of trauma. Supporting this theory is the finding that the medullary contents of the long bones embolize to the pulmonary circulation if intramedullary pressures are elevated. The second theory proposes that these emboli form as a result of changes in the physical state of lipids in the blood. The fact that pulmonary fat emboli are seen in nontraumatic inflammatory conditions, such as osteomyelitis, supports this theory. The issue may be more complicated, since there is no reason why the processes espoused by the two theories could not both play a role.

The treatment and prevention of hypotension and hypoxemia associated with the insertion of prostheses center around adequate hydration and oxygenation of all patients prior to the implantation procedure. These measures often reduce the severity of the above effects or reduce them to the level of clinical insignificance.

**Treatment of Cement Implantation Syndrome**

Anesthetic management of cement implantation syndrome necessitates supporting the cardiovascular system and treating a state of acute right heart failure. The first step includes administration of 100% inspired oxygen and aggressive volume support. Invasive hemodynamic monitoring should be instituted early, in view of the potential for severe pulmonary hypertension, impaired cardiac output, and to guide inotropic support. Early placement of a pulmonary artery catheter may be needed in order to
utilize selective pulmonary vasodilators and assess the effects of high levels of positive end-expiratory pressure in extreme circumstances.

**CEMENTED VERSUS NONCEMENTED HIP ARTHROPLASTY**

**Background**

In the past several years, improvements in prosthetic devices and surgical techniques have made hip arthroplasty a more durable and successful therapy (see Chap. 10). Another benefit of some of these advances is that not all hip arthroplasties require cementing. In fact, there is increasing evidence that, in selected patients, arthroplasty procedures may be performed without bone cement. Because of the close interaction between surgical technique and anesthetic management of the patient undergoing hip arthroplasty, it is important that the orthopaedic anesthesiologist should understand the issues involved in the surgical approach and advocate, in consultation with the surgeon, the best technique for a particular patient. The anesthesiologist must inform the surgeon of any specific concerns he or she has in regard to the use of bone cement and its physiologic effects. Likewise, only through an understanding of the concerns of the surgeon can the anesthesiologist best serve the patient’s needs. To this end, we present some information on the immediate physiologic effects of MMA bone cement as well as the ability to anticipate those effects and knowledge of how to treat and avoid adverse outcomes, the orthopaedic anesthesiologist can better serve his or her patients as well as our orthopaedic colleagues.

**SUGGESTED FURTHER READING**


