A Review Paper

Fat Embolism and Respiratory Distress Associated With Cemented Femoral Arthroplasty

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Abstract

Embolization of fat and marrow contents results from increased intramedullary pressure generated during insertion of an intramedullary implant such as a total hip prosthesis or an intramedullary nail. Embolization is accentuated when the implants are inserted using cemented techniques. These embolic events, observed by transesophageal echocardiography, correlate with hemodynamic changes suggesting pulmonary embolism.

The ability of patients to tolerate these cardiopulmonary changes depends on both baseline pulmonary function and quantity of embolic debris delivered to the pulmonary vasculature during the operation. Patients with good pulmonary function can tolerate the embolic load associated with implantation of a cemented implant and will demonstrate little cardiopulmonary compromise. Patients with poor pulmonary reserve may be unable to withstand the showering of debris resulting from this procedure and are at risk for hypoxia, cardiopulmonary dysfunction, and possibly death.

Measures to remove marrow contents and reduce intramedullary pressure during cemented femoral arthroplasty or to switch to an uncemented technique may minimize the cardiopulmonary risk incurred by this group of patients.

Hypoxia, hypotension, and cardiopulmonary arrest—rare but potentially devastating complications of total hip arthroplasty—have been attributed to embolization of intramedullary fat and marrow contents.[1,2] Presentation of this “fat embolism syndrome” may range from the classic but rare triad of hypoxia, petechiae, and mental status changes to fulminating pulmonary and systemic marrow embolization, right ventricular failure, and circulatory collapse.[2-4] Identifying patients at increased risk for this syndrome and taking appropriate measures to diminish this risk will reduce incidence of this potentially fatal complication of hip arthroplasty.

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Clinical Presentation and Initial Treatment

The incidence of fat embolism syndrome is less than 1%.[2] The most frequent manifestation of this syndrome is respiratory distress with arterial hypoxemia unresponsive to oxygen therapy together with dyspnea and tachypnea often requiring mechanical ventilation.[5] A petechial rash on the conjunctivae, oral mucous membranes, and skin folds of the axilla may be seen in 60% of cases. Neurologic changes, also frequent, range from mental confusion to coma.[1-4] This syndrome most commonly occurs after lower extremity trauma, intramedullary reaming, and implant insertion. Treatment involves adequate resuscitation and respiratory support ranging from supplemental oxygen to mechanical ventilation. Almost 40% of patients require mechanical ventilation. Pulmonary function usually returns within 1 week.[1-4]

It may be difficult to distinguish fat embolization from a pulmonary embolism. Timing is often the key to differentiation. Fat embolization occurs relatively early, within 24 hours of lower extremity fractures and perhaps even earlier (within a few hours) after surgical procedures requiring intramedullary reaming and insertion techniques. A pulmonary embolism usually develops from a deep venous thrombus. Development of the thrombus requires a period of venous stasis and a hypercoagulable state. Pulmonary embolization is usually observed 72 hours to 1 week after trauma or extremity surgery. Earlier embolization may be noted in patients who had a deep venous thrombosis before trauma or surgery. Clinically, petechiae may be noted in fat embolization but not pulmonary embolization.[1,2,6]

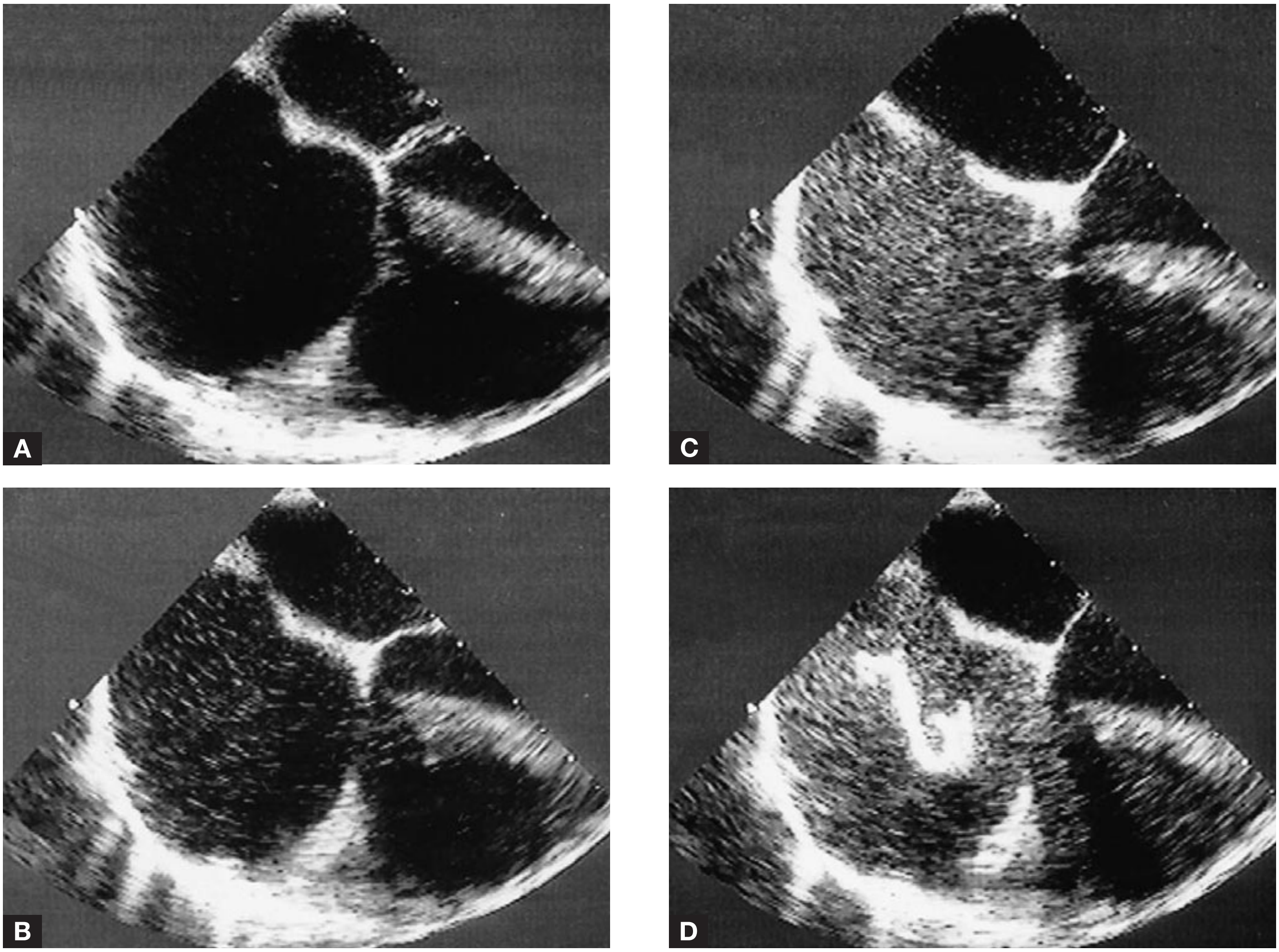

Figure 1. Transesophageal echocardiograms obtained during total hip arthroplasty show the main echogenic patterns. **(A)** Grade 0—no emboli or small echogenic particles evident. **(B)** Grade 1—a few fine emboli are seen. **(C)** Grade 2—a cascade of fine emboli or embolic masses (diameter, ≤5 mm) is evident, and the right atrium is opacified with echogenic material. **(D)** Grade 3—fine emboli are mixed with large embolic masses (diameter, >5 mm) or with serpentine emboli. Reproduced with permission from Pitto RP, Koessler M, Kuehle JW. Comparison of fixation of the femoral component without cement and fixation with use of a bone-vacuum cementing technique for the prevention of fat embolism during hip arthroplasty. A prospective randomized clinical trial. *J Bone Joint Surg Am.* 1999;81(6):831-843.[26]

Pathogenesis

The increase in intramedullary pressure caused by mechanical compression of the medullary canal during stem insertion is the most critical factor contributing to fat and marrow intravasation.[7-11] Degree of embolization is higher with insertion of cemented stems versus uncemented stems.[7,8,12] In canine models, more intramedullary pressure was generated with insertion of cemented versus uncemented femoral components.[8,11] In a biomechanical study, insertion of stems into high-viscosity cement resulted in increases in intramedullary pressure (as high as 187%).[7] Insertion of cemented implants generated many pulmonary emboli and significant cardiopulmonary changes, including decreased arterial oxygen tension, increased pulmonary artery pressure, increased pulmonary shunting, and decreased systemic vascular resistance; these changes were not seen with insertion of an uncemented implant.[8,11,13-16] Similarly, Ries and colleagues[12] observed 28% increases in intraoperative pulmonary shunt values with insertion of cemented femoral components; shunt values did not change when components were inserted without cement. These shunt values increased significantly over postoperative day 2 in patients who received a cemented implant.

Transesophageal echocardiography (TEE) has revealed larger and more prolonged embolic cascades with cemented versus uncemented arthroplasty (Figures 1A–1D). The measured pulmonary and hemodynamic responses showed a direct correlation with the quantity of emboli imaged in the atria.[13,14,17] In a study using TEE in 111 operations that included medullary reaming for acute femoral and tibial shaft fractures, pathologic femoral shaft fractures, and hemiarthoplasty of the hip, Christie and colleagues[13] observed embolic events in 97 procedures. Ninety-six percent of patients with severe embolic responses as seen on TEE underwent cemented hemiarthroplasty or nailing of pathologic lesions of the femur. The authors noted persistence of these embolic responses, which correlated with arterial oxygen desaturation, for up to 1 hour after the operation was completed. In 11 of 14 samples taken from the right atrium, fat was identified when there had been visible echogenic signals, and in 1 of 7 samples fat was identified when these signals were absent, suggesting that the echogenic responses are likely marrow fat.

The mechanism by which these emboli create cardiopulmonary dysfunction is unclear but may involve local pulmonary damage and systemic factors, including generation of a thrombogenic state. Sharrock and colleagues[16] noted that circulating indices of thrombosis and fibrinolysis, such as thrombin–antithrombin complexes and D-dimers, increased significantly during insertion of the femoral component. The increase was larger with use of a cemented versus uncemented femoral component. After cemented femoral arthroplasty, reduction of the hip joint resulted in increased pulmonary artery pressure, suggesting pulmonary embolism; no changes in pulmonary artery pressure were noted after noncemented hip arthroplasty.

Risk Factors

Although embolization of marrow contents is common after cemented femoral arthroplasty, not all patients who undergo this procedure experience cardiopulmonary dysfunction. Patients with normal baseline pulmonary function are likely able to tolerate embolic showers of fat and marrow as well as local and systemic inflammation created by this process. Respiratory distress may result from a dose-dependent “second hit” from embolized elements to a previous pulmonary injury.[18] Alternatively, respiratory compromise may result from massive embolization of marrow debris, as in metastatic disease of the femur, thus overloading a relatively normally functioning pulmonary system.

An analogous situation arises in a polytrauma setting in which a patient sustains a femur fracture and a pulmonary contusion. Such a patient appears to sustain further pulmonary injury and develop respiratory distress after acute reamed intramedullary nailing.[18] “Damage control surgery,” with acute external fixation of the femur and delayed conversion to an intramedullary nail after the pulmonary contusion has resolved, avoids inflicting an acute second pulmonary hit when there is preexisting pulmonary injury. This technique has resulted in better intraoperative and postoperative cardiopulmonary function and less systemic inflammation in patients with polytrauma.[19-21] Consistent with this notion, patients with preexisting chest injuries undergoing intramedullary reaming or hip hemiarthoplasty experienced worsening of pulmonary function despite minimal echogenic signals, suggesting that this subset of patients may be sensitized to a second pulmonary hit from embolized marrow.[13]

Patterson and colleagues[22] reported on 7 patients who experienced cardiac arrest during hip arthroplasty with a cemented long-stem femoral component. Four patients died in the operating room. The authors identified 4 factors common to these patients: advanced age, osteoporotic bone, a previously undisturbed intramedullary canal, and use of a long-stem femoral component with several batches of methylmethacrylate. Introduction of long-stem femoral components into large quantities of cement will generate high intramedullary pressure over a larger surface area and result in significant fat and marrow intravasation. In previously uninstrumented canals, there is a larger volume of marrow debris available for dissemination after cementing. In osteoporotic bone, vascular channels are enlarged, which facilitates embolization of large quantities of debris. This embolized debris likely acts as a second pulmonary hit and severely compromises the already diminished respiratory function of elderly patients. Patterson and colleagues[22] recommended invasive hemodynamic monitoring when these conditions are present.

Herrenbruck and colleagues[23] reported on 55 patients who underwent cemented long-stem femoral arthroplasty for metastatic disease or revision hip surgery. Sixty-two percent of these experienced adverse events, including hypotension, sympathomimetic administration, and oxygen desaturation. The authors noted that patients with metastatic disease, uninstrumented femurs, stem lengths of more than 200 mm, and preexisting cardiopulmonary conditions were at increased risk for these adverse events after long-stem femoral arthroplasty. Patients with metastatic disease of the bone being operated on are thought to have abnormal vasculature that facilitates embolization during cementing of a femoral implant. Furthermore, long stems are used in the metastatic femur for stability, thus increasing the intramedullary pressure and the volume of debris disseminated. Patients with metastatic disease or other underlying medical conditions likely have compromised pulmonary function secondary to pulmonary metastases, for example. These patients are less capable of tolerating a second pulmonary hit from embolized marrow elements.[23] Of note, clinical adverse events have not been reported after insertion of long-stem uncemented femoral components in revision hip arthroplasty.[24]

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Prevention Techniques

Because adverse pulmonary and circulatory changes in cemented hip arthroplasty have been related to volume of marrow emboli, it has been proposed that removing the marrow load with pulsatile lavage will reduce the incidence of these complications.[13,14,17] In a canine study, pulsatile lavage before insertion of the implant into cement reduced the magnitude of hypotension as well as the decreases in cardiac output that occur during cemented femoral arthroplasty.[15] Patients who received thorough saline intramedullary lavage before cemented hemiarthroplasty for hip fracture had a significant reduction in duration of the embolic response as seen on TEE and less disturbance in end-tidal CO_2 levels and oxygen saturation.[17]

Introduction of vent holes into the medullary canal may decrease intramedullary pressure and reduce the incidence of fat embolism. Venting with a 4.5-mm drill hole in the proximal femur reduced proximal intramedullary pressure by 70%; venting the distal femur reduced distal pressure by 90%.[25] However, this technique has not been proved to relieve intramedullary pressure in clinical practice. There are also concerns about cement escaping through the vent hole, reducing the thickness and integrity of the cement mantle, and potentially injuring surrounding soft tissues.[9,10]

A technique we have used in the metastatic femur is to insert cement retrograde through a distally placed vent hole with the femoral stem partially inserted. After the cement is introduced, the stem is slowly advanced to its final depth, allowing residual cement to escape through the vent hole. Although unproved, this technique may minimize the increase in intramedullary pressure associated with stem insertion into cement. This technique may not be applicable in hip arthroplasty for arthritis because in that setting the integrity of the cement mantle is more critical than in the metastatic setting.

Pitto and colleagues[26,27] have described a bone-vacuum cementing technique to limit fat embolization during cemented hip arthroplasty. They conducted a prospective, randomized clinical trial to examine femoral arthroplasty performed using 1 of 3 techniques: uncemented arthroplasty, conventional cemented arthroplasty, and arthroplasty with a bone-vacuum cementing technique. A suction of –80,000 pascals was applied to a 4.5-mm-diameter cannula placed along the linea aspera and a distal 4.5-mm-diameter cannula placed in the femoral shaft to create a vacuum in the medullary canal during cementing and stem insertion (Figure 2).[26] Severe embolic events were noted in 85% of the patients in which the femoral stem was inserted with a conventional technique. No embolic events were noted in patients who underwent uncemented arthroplasty. Stem insertion with the bone-vacuum cementing technique prevented embolic phenomena in 95% of the patients. Although hypotension, arterial oxygen desaturation, and pulmonary shunt increases were significant in patients who underwent conventional cemented femoral arthroplasty, no changes in these parameters were noted in patients who underwent femoral arthroplasty with the uncemented or bone-vacuum cementing techniques.[26] The authors stated that they had not had a femoral fracture from potential stress risers created by the vent holes in more than 130 patients who had undergone this procedure.[26] This technique also reduced incidence of postoperative deep-vein thrombosis during cemented femoral arthroplasty, presumably by reducing marrow embolization of tissue thromboplastin and subsequent thrombogenesis.[28]

Figure 2. Positions of the 2 cannulae used in the bone-vacuum cementing technique. The proximal cannula is placed posteriorly between greater and lesser trochanters along the projection of the line aspera. A permeable synthetic plug is placed at the level of the distal unicortical venting hole and fixed with the threaded tip of the cannula. Reproduced with permission from Pitto RP, Koessler M, Kuehle JW. Comparison of fixation of the femoral component without cement and fixation with use of a bone-vacuum cementing technique for the prevention of fat embolism during hip arthroplasty. A prospective randomized clinical trial. *J Bone Joint Surg Am.* 1999;81(6):831-843.[26]

"In certain circumstances, it may be prudent to avoid cementing entirely."

In implantation of long-stem cemented components, principles derived from reamed femoral nailing are directly applicable. Using reamers with deep cutting flutes, shorter heads, and narrow driver shaft diameters and reaming at a low driving speed and high revolution rate minimized the increase in intramedullary pressure and marrow embolization seen on TEE.[29-32] Reaming with a device that simultaneously irrigates and aspirates the marrow cavity may reduce the marrow contents available for embolization. In sheep in which unilateral pulmonary contusions were generated, this type of reamer (RIA; Synthes, Paoli, Pa) minimizes increases in pulmonary permeability, pulmonary edema, and systemic inflammation associated with reamed femoral nailing.[33]

In certain circumstances, it may be prudent to avoid cementing entirely. Given the significant increases in pulmonary shunting in patients who underwent cemented femoral stem implantation compared with patients who underwent uncemented stem implantation, Ries and colleagues[12] suggested that the patient's ability to tolerate a significant increase in pulmonary shunting should be a critical preoperative consideration when choosing between uncemented and cemented femoral arthroplasty. As adverse cardiopulmonary events have not been reported after insertion of long-stem uncemented components in revision hip arthroplasty, these components may become the implants of choice in patients with low pulmonary reserve.[24]

Conclusions

Embolization of fat and marrow contents is the result of increased intramedullary pressure generated by introducing the femoral component into cement. The respiratory and hemodynamic consequences of this procedure depend on the patient's preexisting pulmonary reserve and the quantity of the disseminated embolic load. Patients with poor baseline pulmonary function are at risk for respiratory and hemodynamic compromise after cemented femoral arthroplasty. Similarly, clinical situations in which large amounts of emboli are delivered to the pulmonary vasculature, such as cementing long-stem components into metastatic, osteoporotic, or previously uninstrumented femurs, may also result in cardiopulmonary dysfunction.

Identifying these potential clinical situations, and instituting preventive measures to minimize intramedullary pressure and potential embolic load, will help avert catastrophic cardiopulmonary complications in cemented femoral arthroplasty.

Authors' Disclosure Statement

Dr. Helfet wishes to note that he is a member of the Board of Directors for RIA/Synthes. The other authors report no actual or potential conflict of interest in relation to this article.

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