Percutaneous Cement Injection for the Palliative Treatment of Osseous Metastases: A Technical Review

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Semin Intervent Radiol 2018;35:268–280

Abstract

Keywords

- cement leakage
- cementoplasty
- polymethyl methacrylate
- complication
- interventional radiology

The technical art to percutaneous injection of polymethyl methacrylate (PMMA) cement for the palliative treatment of osseous metastases is not without pitfalls. Pathologic fracture, cortical bone erosion, large lytic tumor, aggressive tumor biology, and tumor vascularity may increase the risk of cement leakage or limit complete consolidation. A calculated and determined approach is often necessary to achieve satisfactory patient-tailored results. This article reviews the challenges and potential complications during the consolidation of osseous metastases. Case examples are presented to facilitate early detection of impending cement leakage, minimize procedural risks, and provide management suggestions for complications. Technical pearls are provided to refine consolidative techniques and improve the comprehensive treatment of painful osseous metastases.

Objectives: Upon completion of this article, the reader will be able to describe technical pearls through case examples to prevent complications and overcome challenges during percutaneous needle injection of bone cement for the consolidation of osseous metastases.

Accreditation: This activity has been planned and implemented in accordance with the accreditation requirements and policies of the Accreditation Council for Continuing Medical Education (ACCME) through the joint providership of Tufts University School of Medicine (TUSM) and Thieme Medical Publishers, New York. TUSM is accredited by the ACCME to provide continuing medical education for physicians.

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The role of image-guided consolidative procedures has expanded to meet the growing prevalence of osseous metastases.^{1,2} Percutaneous injection of bone cement has proven applicability as a palliative measure for painful osseous metastases and as a preventative measure for impending pathological fractures.^{3–5} Treatment goals include pain control and preservation of functional activities, which can translate to improved quality of life, decreased opioid dependence, decreased morbidity associated with immobility, and lower overall healthcare costs.^{6–10}

To achieve palliative results, PMMA cement is injected to fortify a pathological fracture line or consolidate a lytic tumor. Established procedures include vertebral augmentation and cementoplasty. Vertebral augmentation encompasses the treatments of vertebroplasty and kyphoplasty, while cementoplasty applies the same techniques outside of the spine.^{11–15} More recently, cement consolidation has also shown additive value during percutaneous screw fixation by

the interventional radiologist.^{16–18} Treatments can be applied in the outpatient setting and do not interfere with the administration of systemic therapies or preclude external radiation treatment.

The highly variable presentation of osseous metastases can create specific procedural challenges for percutaneous cement injection techniques that may result in suboptimal consolidation or precipitate complications. This manuscript provides an overview of the clinical and technical approach to image-guided percutaneous cement injection procedures for osseous metastases. The treatment challenges and complications are detailed through case examples. Clinical management of complications is briefly discussed. Several practical technical tips are illustrated to improve cement consolidation and prevent complications associated with cement leakage outside of the osseous margin.

Selection Error: Avoiding Maslow's Hammer

While cement injection provides a valuable palliative method to treat mechanical pain related to osseous metastases, the application is not omnipotent. Lytic metastases cause musculoskeletal pain not only by undermining osseous stability and the integrity of muscle and tendon insertions, but also by causing increased intraosseous pressure, exerting periosteal stretching, compressing adjacent nerves and muscles, and inciting cytokine-mediated inflammation.^{19,20} Appropriate

patient selection is fundamental to ensure treatment success by cement consolidation. Incomplete clinical workup will result in poor patient selection that portends negligible pain relief despite the best procedural technique.

Clinical evaluation should include a focused history and physical exam with inventory of daily narcotic usage and quantification of preprocedure pain by a validated pain scale. Non-tumoral causes of pain should be excluded. Symptoms more consistent with neurogenic pain, bursitis, or arthritis might be more appropriately treated with non-invasive measures or focal steroid injection. Procedures should be directed towards tumors that cause mechanical pain exacerbated by movement or weight bearing activities. If resting pain is the only source of tumor-related pain, then locoregional treatments might be more appropriate.

In treatment of bone tumors associated with mixed mechanical and resting pain, a complementary locoregional treatment may be indicated for a more durable treatment effect.^{21–24} For example, aggressive tumor biology may suggest a concomitant locoregional treatment to decrease tumor encroachment on a critical structure or prevent tumor growth from undermining the cement (►Fig. 1). Lastly, the character and location of tumor should be evaluated during preprocedure work up. Lesions with predominantly lytic characterization are conducive to cement consolidation, while sclerotic metastases can prove resistant due to a poorly porous nature (►Fig. 2). The tumor location can help predict

Fig. 1 Metastatic renal cell carcinoma throughout the T9 vertebral body (a) and effacement of the thecal sac without symptomatic cord compression (b). Ablation for additive pain palliation through locoregional tumor control and attempt to prevent skeletal-related event of spinal cord compression (c), followed immediately by vertebroplasty (d, e).

Fig. 2 Cementoplasty of mixed sclerotic metastasis to the left superior acetabulum from breast adenocarcinoma (a). Mixed osteolytic-osteoblastic composition did not accommodate cement injection (b). Arterial cement embolus occurred into the superior gluteal artery (b, wide arrow) that migrated into distal branches (b, narrow arrows). The patient had no change in symptoms, without pain palliation or exacerbation. Incident note is made of cement retained from needle track (b, arrowhead).

palliation effects. As bone cement provides resistance to compression forces, palliative outcome is greater in weight-bearing locations that are subjected to predominantly axial loads. Conversely, palliative effect may be nominal for tumor locations in long or flat bones that are subjected to substantial torque or flexion stresses (►Fig. 3). These locations might benefit from additional reinforcement by percutaneous screw or intramedullary rod placement.

Needle Access Complications

Needle manipulation may result in complications from direct traumatic injury to artery, nerve, or muscular tendon.^{25,26}

The percutaneous approach should be carefully considered and an appropriate image guidance modality should be employed to optimize visualization of critical structures along the needle trajectory. Several techniques may be used to avoid visible critical structures. Oblique needle trajectories can be facilitated with real-time ultrasound guidance, CT gantry angulation, or needle guidance software. Displacement techniques may be applied in a similar fashion as championed during percutaneous thermal ablation.²⁷ In the event of muscle or nerve injury, the cornerstone of treatment is nonsteroidal anti-inflammatory agents or steroids depending on severity. Arterial injury may require endovascular, percutaneous, or surgical repair (►Fig. 5). Other complications associated with needle access include infection and tumor seeding. Appropriate sterile technique is typically an adequate preventative measure. Some practices add a single dose of intravenous antibiotics that cover skin flora in the preprocedure setting. Tumor seeding from needle

manipulation is rare, with few case reports (►Fig. 4).^{28,29} Needle trajectory should be considered. The occurrence of tumor seeding in relation to tumor type or timing of cement consolidation in relation to systemic or radiation therapy has not been evaluated.

Periosteal Cement Extrusion

Cement leakage is a common complication of percutaneous cement procedures, and occurs more frequently during the treatment of malignant disease compared with osteoporotic disease.^{30,31} Symptoms tend to result from direct compression on adjacent nerves or muscle.³²

Cement leakage into the surrounding soft tissues may occur in multiple presentations depending on the location of the procedure and needle approach (►Fig. 6). During vertebral augmentation, posterior extrusion of cement into the spinal canal may result in epiduritis or canal narrowing. Similarly, leakage of cement may also compress peripheral nerves such as the neuroforaminal or sciatic nerves. While small foci of cement leakage are typically asymptomatic, significant sequela can result in the event of motor, sensory, or sympathetic ganglia nerve impingement.³³ Leakage into the intervertebral disc space are typically asymptomatic; however, there.^{34,35} Similarly, a small amount of leakage into a joint space is likely of little clinical consequence; however, risk of subchondral cortical erosion increases with larger volume leakage. Cement that extrudes into muscles or is retained upon needle retraction may cause persistent inflammation with muscle activity, particularly if located near tendon insertion sites.

Fig. 3 Fracture occurs despite preventive consolidation with cementoplasty in locations subjected to substantial tension or torque stresses: acetabular roof (a), superior pubic ramus (b), femoral neck (c), and iliac crest (d).

Fig. 4 Lytic renal cell metastasis to the iliac pelvic brim resulted in severe pain limiting weight bearing (a). Due to high risk of fracture, fixation by internal cemented screw was performed (b). Tumor seeding occurred at 9 months, through the needle track (c).

Fig. 5 Metastatic renal cell carcinoma to the left acetabulum resulted in extensive lytic destruction (a: oblique sagittal view, b: axial view). Treatment was pursued with particle embolization (c) for pain palliation followed by fixation with internal cemented screw placement (d: screw insertion via a transchial approach with cementoplasty via a lateral transgluteal approach). Significant pain palliation achieved with consolidation (e). Persistent postprocedure pain in the gluteal muscles along cement needle trajectory prompted CT evaluation that identified pseudoaneurysm (f, g) that was likely the result of needle trauma during cementoplasty. Definitive treatment with direct percutaneous thrombin injection (h).

Treatment of cement leakage is typically conservative with nonsteroidal anti-inflammatory agents or steroids. Image-guided incision and removal may be pursued for superficial locations if muscular or nervous symptoms persist (►Fig. 7). Surgical decompression may be required in the small cohort of patients with continued pain related to cement compressing upon a nerve or muscle.^{31,36}

Intravascular Cement Leakage

Intravenous cement displacement through the periosteal venous plexus has been reported with incidence up to 25%.^{26,37} Cement leakage to an azygous vein portends a higher risk of migrating to the lungs (►Fig. 8).³⁸ The use of intravertebral venography prior to cement injection may

Fig. 6 Cement extrusion into surrounding soft tissues. (a) Leakages into disc spaces. (b) Posterior extrusion of cement into the spinal canal. (c) Cement leakage travels up through the tip of cannulated screw to leak into soft tissues at screw head. (d) Leakage into hip joint. (e) Leakage in the surrounding muscles.

have some preventative role in highly vascular lesions with expected venous shunting, although the value is controversial and not widely practiced.³⁹ The majority of pulmonary cement emboli are small, asymptomatic, and do not require any treatment. A few case reports describe grave cardiopulmonary complications from large pulmonary emboli.^{40–43} In addition, there has been a case report of cardiac perforation caused by a needle-like cement embolus after vertebroplasty⁴⁴ and a case of paradoxical cerebral arterial embolization.⁴⁵ The degree of vascular compromise guides treatment decision between systemic anticoagulation and retrieval by endovascular or open surgical methods.^{40,46–48}

Intra-arterial cement extrusion is a rare but potentially serious complication. An arterial embolus during vertebral augmentation may migrate into the aorta and result in distal emboli into the mesenteric, renal, or lower extremities (►Fig. 9).^{49,50} Similarly, cement injection outside of the spine may result in arterial cement embolus into an adjacent muscular artery with concern for tumor dispersal (►Fig. 3). Possible predisposing risks include altered flow dynamics associated with highly vascular lesions, needle tip positioned in close proximity to an artery or in a nearby vascular shunt, and higher pressure cement injection. Immediate management should include clinical and imaging assessment to document acute symptoms and extent of arterial embolism. In the event of end-organ or distal extremity arterial cement embolus, anticoagulation should be initiated and vascular surgery consultation should be obtained.⁵¹

Prevention of Cement Leakage

Multiple techniques may be employed to minimize risk for cement leakage.⁵² Careful monitoring by image guidance is the most important means to decrease the risk of cement leakage into the periosteal tissues. Cement injection should be stop at first sign of impending cement leakage; however, early cement leakage should not deter completion of consolidation. Multiple needles or procedures may be required to achieve desired effect (►Figs. 10 and 11).⁵³

During cement injection, Poiseuille's law of fluid dynamics can guide understanding of the relationship between flow rate, pressure, needle dimensions, and liquid viscosity (►Fig. 12). Factors that decrease the flow rate of bone cement exiting the needle, and hence improve controllability, include decreased pressure and increased liquid viscosity. Pressure may be decreased by the use of needles with the largest diameter safely applicable and the shortest needle length affordable based on trajectory. While liquid viscosity of cement is easily attained by patiently waiting, this may result in challenges to advance sufficient quantities of cement unless a mechanical cement injector is used.^{54,55}

Several special approaches have been championed to minimize cement leakage from extensively eroded bone. Balloon catheters have been used to control cement flow.⁵⁶ These may be employed to create a cavity within the osseous metastasis to improve focal consolidation. Alternatively, balloon catheters may also be employed to create a barrier

Fig. 7 Metastatic breast cancer to T10 with painful compression fracture treated with vertebroplasty (a). Despite satisfactory relief of original pain, patient noted a new focal back pain at the site of needle entry. On lateral radiograph, a tail of cement was noted in the paraspinal muscles, likely left in situ upon removal of needle (b). Pain was relieved with image-guided removal of the majority of the tail cement with small incision and forcep retraction (c,d).

Fig. 8 Pathologic compression fracture of L2 treated with vertebroplasty with cement displacement (white arrow) into the periosteal venous plexus (a). Small asymptomatic pulmonary cement emboli (white arrow head) on chest X-ray, after vertebroplasty (white arrow head) at T7 level (b).

Fig. 9 Metastatic breast cancer to the L1 vertebral body (a) treated with CT-guided vertebroplasty. Cement leakage into a segmental artery and aorta noticed during the procedure (b). Arterial leakage via the aorta to the left kidney (c–e) and left lower extremity (f–h). Patient remained asymptomatic without sequela to the renal function or left leg. A cautionary 1-month course of anticoagulation was completed until documentation of imaging and clinical stability.

to cement flow, which can be removed before cement hardens. The application of cryoablation provides an innovative temporary measure to create an effective barrier from a wall of frozen tissue (► **Fig. 13**).⁵⁷ Polyetheretherketone (PEEK) coiled metallic implants have been suggested to provide a permanent barrier technique that can be used during vertebral augmentation in the setting of extensive destruction of the posterior vertebral wall.⁵⁸ In a similar fashion outside of the spine, stents have been employed to create a channel to retain cement flow within a defined location (► **Fig. 14**).⁵⁹

Cardiopulmonary Complications

Although rare, cement injection may result in cardiovascular complications. Large or multiple cement emboli to the

pulmonary arteries may result in increased right heart strain. Severe symptoms may require surgical decompression. In a similar mechanism, cement injection may result in displacement of intraosseous bone marrow into the periosteal venous plexus that migrates to the pulmonary circulation as a fat embolus.^{60–63} In the event of fat embolism, the patient classically presents with respiratory insufficiency, neurologic manifestation, and petechial rash after an asymptomatic interval of 12 to 72 hours according to Guard's criteria.⁶⁴ To prevent symptomatic fat embolisms, recommendations suggest limiting cement injection to less than 30 mL per intervention.⁶⁵ Treatment of symptoms suspected to be a result of fat embolus includes supportive measures with oxygenation and short course of steroids. Lavage techniques and venting needles have been proposed to reduce

Fig. 10 Pathologic compression fracture of the L2 vertebral body from metastatic breast cancer (a, b). Extensive destruction resulted in incomplete cement consolidation on initial attempt via traditional transpedicular approach (c, d) due to concern for impending cement leakage. A second attempt via an oblique approach through the vertebral body (e) provided complete consolidation (f: axial view, g: coronal view, h: coronal view).

Fig. 11 Metastatic thyroid cancer with extensive lytic destruction in the pelvis (a, b). Palliative consolidation with staged fixation by internal cemented screw placement (c). Cementoplasty was performed through more than 25 needles over three treatment sessions (d) to prevent cement leakage and optimize consolidation (e, f).

$$Q = \frac{\pi \Delta P r^4}{8 \eta l}$$

Q = flow rate
 P = pressure
 r = tube radius
 l = tube length
 η = liquid viscosity

Fig. 12 Poiseuille's law of fluid dynamics. Flow rate, and hence procedural control, can be improved with larger diameter needle, shorter needle length, and greater liquid viscosity.

risk of cement leakage and fat emboli by reducing intravertebral resistance and injection forces.⁶⁶ Lastly, hypotension may result from biochemical interactions with the cement monomers, release of vasoactive mediators into the circulation, and possible vasoregulatory function of sensory nerve endings in the bones.^{67–69} Symptoms are typically transient in effect and generally do not require treatment. The procedural nurse or anesthetist should be forewarned immediately before cement injection to anticipate transient hypotension or bradycardia.

Fig. 13 Large lytic metastasis to the iliac bone with extensive cortical destruction (a, b). Structural integrity of the destroyed bone was restored with percutaneous placement of cannulated screw followed by cement consolidation. Due to the extensive cortical erosion, cement was likely to leak immediately upon injection. To control and contain cement, an ice wall barrier was created lateral to the iliac bone four cryoablation probes and set to low freeze-stick (c–e: coronal views, f and g: axial views). The ice wall barrier effectively contained cement within the lytic bone and minimized leakage into the surrounding tissues (h and i).

Fig. 14 Metastatic lung cancer to the iliac bone with extensive lytic destruction and cortical erosion along the superior and lateral iliac border (a–d). Palliative treatment performed with fixation by internal cemented screw placement (e, f). Due to concern for cement leakage through the extensive cortical erosion, a aetallic vascular bare-metal stent was deployed in parallel to the screw along the cranial aspect. The stent created a channel for controlled cement distribution and minimized cement leakage (e and f—arrows).

Conclusion

Percutaneous cement injection has valuable palliative applications in the treatment of metastatic osseous disease; however, the technique is not without challenges and pitfalls. Complications from cement injection techniques can be attributed to poor patient selection or application, traumatic injury from needle trajectory, extraosseous cement leakage into surrounding soft tissues, intravascular cement emboli, displacement of bone marrow with fat emboli, and transient cardiovascular reaction to cement. Understanding potential complications optimizes patient selection, improves technique, and guides postprocedural management.

The reader is referred to multiple prior *Seminars in Interventional Radiology* articles for further information regarding complications involving cement applications.^{70–72}

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