Percutaneous Cementoplasty

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ABSTRACT

Cementoplasty includes percutaneous procedures like vertebroplasty, kyphoplasty, osteoplasty, and sacroplasty. Bone packing with cement aims to treat or prevent vertebral and extraspinal pathological fractures and relieve pain in patients with osteoporosis and bone metastases. The authors outline the accepted and newer indications for patient selection and present the fundamentals of image-guided lesion access and cement injection. Practitioners should evaluate each patient carefully and have a thorough knowledge of the anatomy, the technique, the expected outcomes, and the potential complications. Detailed informed consent and multidisciplinary decision making are recommended. Understanding of the particular advantages and limitations of the various modern filler materials is also crucial for a successful and uncomplicated procedure. Future developments include new mechanical devices for effective restoration of vertebral height, as well as the introduction of osteoconductive and osteoinductive cements that will be able to promote more physiological bone healing.

KEYWORDS: Osteoporosis, bone metastasis, cementoplasty, vertebroplasty, osteoplasty

Objectives: Upon completion of this article, the reader should be able to list the indications, technique, results, and complications of percutaneous cementoplasty procedures. In addition, readers should be able to state the advantages and disadvantages of the various modern filler materials.

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In modern practice, cementoplasty refers to the percutaneous application of cement to stabilize the spine and the skeletal system of the extremities, where the term *cement* is used to describe a wide variety of viscous materials injected for consolidation of painful osteolytic lesions. Cementoplasty is broadly used to include procedures like vertebroplasty, kyphoplasty, osteoplasty, and sacroplasty.^{1–3} Bone packing with cement aims to treat or

prevent pathological fractures and pain in patients with vertebral and extraspinal osteolytic lesions.⁴ Percutaneous vertebroplasty, initially described in the late 1980s by Galibert and colleagues to treat a painful, aggressive vertebral hemangioma,⁵ marked the birth of percutaneous vertebral augmentation procedures and has revolutionized the field of cementoplasty procedures ever since. Cementoplasty generally involves the image-guided

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injection of radiopaque cement for the stabilization of painful osteoporotic or malignant vertebral compression fractures and aggressive vertebral hemangiomas.^{1-4,6-8} The procedure is performed by well-trained and experienced practitioners, including interventional radiologists, orthopedic surgeons, and neurosurgeons. The present seminars' review outlines the accepted and newer indications for the procedure, presents the fundamentals of the technique, reports the expected results, and critically reviews the various types of cement available in the market, emphasizing details and technical aspects of a safe and successful cementoplasty procedure. Published standards of practice and guidelines for the performance of percutaneous vertebroplasty are also highly recommended to the reader.^{2,9}

PATIENT SELECTION

Nontraumatic vertebral compression fractures, defined as reduction in the individual vertebral body height by 20% or 4 mm,¹⁰ are caused by osteoporosis or various malignant etiologies and produce debilitating back pain with a devastating impact on the patient's general quality of life.¹¹ It is estimated that osteoporosis affects more than 10 million people and afflicts more than 700,000 vertebral compression fractures in the United States alone.^{2,12} Spinal metastatic disease and multiple myeloma are the predominant neoplastic causes of vertebral compression fractures.^{1,2,4,6} Of note, collapsed thoracic and lumbar vertebrae result in spinal kyphotic deformities and are related to a considerable added risk of mortality compared with age-matched controls, because of compromised pulmonary function.^{1,13}

Accepted indications of percutaneous cementoplasty or vertebroplasty are painful vertebral fractures refractory to conservative medical treatment.^{1,3,4,6,8} In case of osteoporosis, excessive doses of opiates or inadequate pain management after a period of at least 3 weeks with regular analgesics is a prerequisite.¹⁴ In case of malignancy, painful osteolytic lesions of metastatic, multiple myeloma, or lymphoma origin can be treated, in parallel with the appropriate protocol of oncological therapy.^{4,9,15,16} Painful metastatic lesions of the sacrum, the acetabulum, the pubic bones, and the femur are also indications for percutaneous cementoplasty because of their weight-bearing properties.¹⁷⁻¹⁹ Patients with aggressive vertebral hemangiomas and giant cell tumors are also candidates for the procedure to achieve tumor devascularization, lesion consolidation, and pain relief.^{20,21} In difficult cases with epidural spread and/or spinal compression, cementoplasty with adjunctive sclerotherapy may be applied alone or preoperatively.^{20,22}

Other suggested indications for percutaneous cementoplasty of the spine include osteonecrosis (Kummel's disease), spinal pseudarthrosis, intravertebral vacuum phenomena, Langerhans cell histiocytosis,

osteogenesis imperfecta, Paget's disease, painful Schmorl's nodes, preoperative reinforcement of the vertebral body or pedicle (pediculoplasty), nonhealing chronic traumatic fractures, and recent burst fractures.^{1,9,23-29} Successful conservative therapy, uncorrectable coagulopathy, local infection, and widespread bone metastases are definite contraindications to the technique.^{1,4} The procedure may be performed with great caution in case of osteolysis or fracture of the posterior vertebral column and if the tumor extends into the spinal canal, because of a considerably higher risk of complications.^{2,3} A detailed medical history and physical neurological examination are required to rule out degenerative causes of back pain and radiculopathy like facet arthropathy, disk herniation, or spinal canal stenosis.^{1,2,4,11} Spinal cord compression with neurological deficits should be dealt with operative decompression and posterior spinal stabilization. The ideal candidate for percutaneous vertebroplasty is a patient who presents within 4 to 6 months of a fracture not improving with conservative medical treatment or has midline nonradiating back pain that increases with weight bearing and that is exacerbated by manual palpation of the spinous process of the involved vertebra.^{3,4,8,11} According to literature, this patient should expect an almost 80% relief of significant pain and improved mobility after cementoplasty.² Cementoplasty remains the cornerstone treatment for osteopenic or osteolytic lesions of weight-bearing bones because of the combined consolidation and stabilization effects. Cryoablation or thermoablation techniques with optional cementoplasty may be applied for pain management in the rest of the skeletal system.^{22,30} The indications and contraindications of percutaneous cementoplasty are outlined in Table 1.

CLINICAL CONSIDERATIONS

Patients with painful osteoporotic fractured vertebrae should be referred for cementoplasty therapy after failure of at least 3 weeks of conservative treatment. Early intervention is justified only in elderly cases with a high risk for decubitus complications like deep vein thrombosis, pneumonia, and decubitus ulcers.^{7,31} Lumbar vertebral lesions generally cause back pain and tenderness in the midline at the level of the fracture, and the pain has a bandlike distribution in the thoracic region. In case of fractures at the level of conus medullaris, the pain may radiate to the hips.^{1,4,6,8} Baseline radiographic studies, thin-section computed tomography (CT) and magnetic resonance (MR) imaging are essential for optimal preoperative planning to identify the level(s) of the fracture, estimate its age, outline the extent of lysis, identify any involvement of the pedicles, evaluate the integrity of the posterior vertebral body wall, and exclude epidural or foraminal tumor spread and retropulsed bone fragments, all of which are associated

Table 1 Cementoplasty Indications and Contraindications**Indications**

Osteoporotic or malignant vertebral compression fractures
 Painful malignant osteolysis of the vertebrae and the acetabulum
 Aggressive vertebral hemangiomas and giant cell tumors
 Painful fracture and osteonecrosis (Kummel's disease)
 Spinal pseudarthrosis
 Intravertebral vacuum phenomena
 Langerhans cell histiocytosis
 Osteogenesis imperfecta
 Paget's disease
 Painful Schmorl's nodes
 Preoperative reinforcement of the vertebral body or pedicle
 Nonhealing chronic traumatic fractures
 Acute vertebral burst fractures

Contraindications

Spinal cord compression
 Response to medical therapy
 Uncorrectable coagulopathy
 Osteomyelitis, discitis, or active systemic infection
 Allergy to cement or other filler materials
 >5 or diffuse bone metastases
 Lack of neurosurgical support

with an increased likelihood of complications.^{1,3,6,11} Fracture or compromise of the posterior vertebral cortex abolishes its protective and insulative properties and predisposes to increased leaks into the spinal canal.

MR imaging with T1, T2, and Short TI Inversion Recovery (STIR) sequences in axial and sagittal planes provide most of the necessary functional and morphological information. Acute, subacute, and nonhealing fractures appear hypointense on T1-weighted images and hyperintense on T2-weighted and STIR images.^{2,3} Because of fat suppression, the STIR sequences are particularly sensitive in the detection of bone marrow edema and metabolically active fractures.^{7,11} Further imaging with gadolinium contrast injection is useful in identifying malignant infiltration and excluding infection.^{2,9} With regard to vertebral hemangiomas, which are typically hyperintense in both T1- and T2-weighted images, an aggressive type that is more often symptomatic and demonstrates low signal on T1- and high signal on T2-weighted images has been described.³² However, the high cost, presence of pacemakers, and severe claustrophobia may limit access to preoperative MR imaging.

In case of multilevel vertebral fractures, bone scan imaging may be helpful to differentiate the symptomatic level from incidentally discovered ones. A bone scan is warranted in case of multiple contiguous fractures and if insufficiency fractures of the sacrum and pelvis are suspected.^{1,9} Of note, increased radioactive tracer uptake is highly predictive of successful pain relief following

vertebroplasty.³³ If cross-sectional imaging shows bone sclerosis, which suggests healing of the fracture, cementoplasty should be discouraged because needle advancement and cement injection may be particularly difficult and suboptimal clinical outcomes are to be expected.¹¹

TECHNICAL CONSIDERATIONS

Percutaneous cementoplasty is generally performed with local anesthetic and neuroleptanalgesia under strict aseptic conditions.^{3,8,34} Prophylactic broad-spectrum antibiotic cover (cefazolin 1 g) is mandatory in immunocompromised patients.² Infiltration with 1% lidocaine to anesthetize the skin entry site, the subcutaneous soft tissues, and the periosteum of the target bone and a combination of intravenous opiate (fentanyl) and benzodiazepine (midazolam) during needle advancement and cement injection achieve adequate analgesia and anesthesia for a successful cementoplasty procedure in the majority of the cases.^{1-4,9} Anesthesiological consult and general anesthesia may be required for larger-bore instruments, as in case of kyphoplasty described later, and for difficult patients with compromised cardiopulmonary function.³⁵ Sedation with continuous propofol infusion titrated to the patient needs has also been suggested.³⁶ Baseline blood count and biochemistry tests, screening of coagulation profile, patient monitoring facilities, and on-site orthopedic or neurosurgical support in the extraordinary case of spinal cord compression should all be available before obtaining informed consent of the patient.^{2,4}

Percutaneous cementoplasty can be divided to two equally important components: first, needle placement and second, cement injection. Well-chosen image guidance is of utmost importance for precise lesion targeting, uncomplicated needle placement, accurate visualization of cement distribution, and early detection of leaks.³⁷ Biplane fluoroscopy or dual guidance with a mobile C-arm placed in front of the CT gantry is suggested, with the latter required in case of difficult to access lesions, as in osteoplasty of extraspinal lesions.^{3,38} Alternatively, a multidetector CT machine with integrated multislice fluoro-CT imaging or an angiography unit with new-generation flat-panel CT imaging may be used according to operator's experience. In any case, the final crucial step of cement injection must be monitored in real time with high-quality fluoroscopy. In our experience, modern rotational angiography units with biplane imaging offer high versatility coupled with high-resolution imaging for the majority of minimally invasive spinal procedures. Biplane fluoroscopy is elemental because it allows simultaneous visualization of two orthogonal planes.¹ Additional cross-sectional imaging with integration of flat-panel CT into the rotational angiography unit is worthwhile for maximum patient safety and operator comfort. Because

of its high spatial resolution, CT guidance is superior in the detection of small cement leaks.^{39,40}

The skin entry point and the needle tract may be decided beforehand on the basis of the preoperative imaging. The patient is typically placed in a prone position for cementoplasty of the thoracolumbar vertebrae and in a supine position for treatment of the cervical spine. Patient positioning for extraspinal cementoplasty may be prone, supine, or lateral decubitus, depending on the exact anatomic location of the lesion. When the patient lies in a prone position, placement of soft pads at the levels of the ankles and the lumbar spine helps straighten the spinal curvature.³⁷ The safest needle pathway in the thoracic and lumbar levels is by a standard transpedicular approach with a medial needle trajectory through the pedicle. Alternatively, an intercostovertebral, a parapedicular, or a paravertebral pathway may be followed if the pedicles are not readily visible on frontal X-ray fluoroscopy because of neoplastic infiltration or fracture and collapse.^{1,3,37,41} An anterolateral approach avoiding injury of the carotid-jugular complex is typically followed in the cervical levels.³⁷ A direct anteroposterior transoral route is proposed for cement injection in the second cervical vertebra.^{42,43} A transdiscal approach from an adjacent lumbar level has been also described.⁴⁴ In case of a compression fracture, at least one-third remaining vertebral body height is necessary for safe needle introduction and cement injection.

Insertion of a large-bore, 10- to 15-gauge, diamond- or bevel-shaped needle begins with the patient in the prone position. The appropriate pedicle is localized with fluoroscopy and appears oval in a straight anteroposterior view with a slight 5- to 10-degree angulation. Once the local anesthetic has taken effect, cortical perforation at the upper and lateral aspect of the pedicle begins with the aid of a surgical hammer and a medial orientation.^{1,3,4,6,37} The needle is advanced slowly under periodic frontal and lateral fluoroscopy with particular attention not to transgress the medial and inferior border of the pedicle, so as to avoid breaching the spinal canal and the underlying foramina, respectively. An advancement angle of 10 to 15 degrees to the midline coronal plane will place the needle within the ipsilateral vertebral body, whereas an angle of 25 to 30 degrees will position the needle closer to the midline. The operator should remember that the vertebrae are circular, and in a lateral projection the most anterior part of the vertebral body is at the midline, so the more ipsilateral the approach of the needle is, the less anterior the needle may be advanced before breaching the anterior vertebral cortex.⁴⁵ CT guidance may be more cumbersome than real-time fluoroscopy, but it allows three-dimensional visualization with exact differentiation of local anatomy and is more effective in achieving the ideal needle trajectory toward the midline.³⁸ For percutaneous vertebroplasty,

the needle tip should be placed medially in the anterior one-third to one-fourth of the vertebral body, as close as possible to the midline.^{1,3,37} In this way, a single unipedicular approach usually suffices for cement consolidation of the whole vertebral body. If optimal cement packing is not achieved from the first approach, then a bilateral bipedicular approach may be performed, at the expense of a prolonged procedure and added risk of cement leak.²² However, no difference has been reported in the clinical results between unipedicular and bipedicular approaches.⁴⁶ We personally prefer to use a 10-gauge beveled vertebroplasty needle for the lumbar, a 12-gauge for the thoracic, and a 15-gauge for the cervical vertebrae. Use of a beveled needle has the benefit of steerability, allowing continuous changes to the orientation of the needle tract. In this way, the medial border of the pedicle is rarely breached, the needle is promptly advanced to the midline, and a bipedicular access is seldom necessary.^{3,4}

For medicolegal issues, we advocate collection of a bone biopsy specimen in all cases as the needle passes through the midthird of the vertebral body.^{1,47} The performance of vertebral venography to opacify venous interconnections and identify potential routes of extravasation before definite injection of the cement remains controversial.^{48,49} Apart from hypervascular lesions like hemangiomas and metastases from thyroid and renal cell cancer, the iodinated contrast washes away too slowly from the vertebral body and might obscure small cement leaks afterward.⁴ Therefore, we would advocate a gentle aspiration from the needle instead of contrast venography to exclude a major venous communication before injection of cement. Cementoplasty of extraspinal lesions of other weight-bearing bones is performed under CT guidance and more than one needle or synergistic bone ablation may be required, depending on the extent of neoplastic involvement.⁵⁰

CEMENT MATERIALS

The principle of pain relief with cementoplasty is based on the consolidation of the weakened and pathological cancellous bone and on the combined chemical and thermal cytotoxic effect produced during cement polymerization. In fact, adequate pain relief may be obtained in metastasis after injection of a volume of only 2 mL of polymethyl methacrylate (PMMA).^{51,52} After successful needle placement in the lesion of interest, cement is prepared according to manufacturer's instructions. PMMA is the most widely used cement with several decades of experience in orthopedic surgery. Older-generation PMMA cements had to be mixed with barium sulfate, tungsten, or tantalum powder because of their inherently low radiopacity.^{3,6} Nowadays, a variety of injectable cements are commercially available for use in cementoplasty procedures, and every practitioner should

Table 2 Different Cement Materials

Polymethyl Methacrylate	Composite Cements	Calcium Phosphate Cements
Methyl methacrylate polymers	Dimethacrylate resins	Calcium phosphate (apatite or brushite)
Good radiopacity	Good radiopacity	Low radiopacity
Low cost	Moderate cost	High cost
Exothermic reaction and coagulation (80–120°C)	Abrupt setting at low temperature (<58°C)	Delayed setting at room temperature
Fibrous tissue encapsulation	Surrounding bone mineralization	Biocompatible and bioresorbable
Recommended for osteoporosis and metastases	Recommended for osteoporosis	Recommended for recent burst fractures

be familiar with their integral differences in terms of chemical synthesis, polymerization times, biocompatibility, mechanical strength, radiopacity, and rheological properties (Table 2). Use of a closed mixing system is recommended to avoid cement contamination and achieve homogeneous mixing and optimal strength without inclusion of air bubbles.³⁴

New PMMA cements have increased radiopacity, but are still prepared with hand-mixing of a polymer powder (methyl methacrylate) and a liquid monomer (methyl methacrylate/dimethyl-p-toluidine) on site.^{53,54} The manufacturer recommends a monomer/polymer ratio of 0.5 mL/g. Custom modification of this ratio or cooling of the mixture in an iced bath may prolong the setting time with decreased viscosity of the mixture. Within 1 minute of its recommended preparation, the PMMA increases its viscosity from thin to thick and pasty. To minimize cement leaks, PMMA must be injected during this pasty polymerization phase.^{2,4} Typically, PMMA has a setting time of 8 to 10 minutes in room temperature of 20°C. In modern clinical practice, ready-to-use PMMA cements are commercially available, allowing safe injection without on-site manipulation of the material. PMMA polymerization is an exothermic reaction and cement temperature reaches 80 to 120°C, which produces local thermocoagulation of tumoral cells, but may also damage healthy adjacent tissues, like neural roots and the spinal cord itself, in case of severe leak. Tissue temperatures as high as 70°C have been recorded during PMMA cementoplasty.⁵⁵ Of interest, PMMA is unreactive to new bone formation, and pathological examination has demonstrated development of a fibrous tissue layer between PMMA and healthy adjacent bone encapsulating the implanted material.⁵⁴

Newer filler materials for cementoplasty are the composite cements and the calcium phosphate cements (CPCs).^{53,54} Composite cements are another type of acrylic glue used since the late 1970s, and composite cement formulations consist of various forms of dimethacrylate resins glycidyl-methacrylate (GMA) or ethyl-methacrylate (EMA). Composite cements were mainly developed to avoid the exothermic reaction coupled with PMMA, but they also have the merits of improved

biomechanical profile and biocompatibility. Composite cements solidify at a low temperature (not exceeding 58°C), have improved fatigue tolerance compared with PMMA, and are followed by a greater degree of surrounding bone mineralization.^{56,57} The downsides are their relatively low viscosity that predisposes to leaks, the higher cost, and the abrupt setting of the material that occurs after ~8 minutes with the risk of the needle getting glued inside the vertebra. Because composite cements lack the cytotoxic exothermic effect, we would not recommend them for the treatment of bone metastases. However, due to the low setting temperature and the superior mechanical properties of composite cements, osteoporotic compression fractures could be the best indication for their use.

CPCs are the most biocompatible and most expensive type of cement available in the market today and are particularly interesting because of their osteoconductive properties.^{53,54,58,59} CPCs consist of calcium phosphate powders dissolved in an aqueous solution. Around room temperature, apatite or brushite crystals precipitate from injectable CPC, which in turn stimulate new bone formation. Histological examination has shown early bioresorption of CPC after 2 weeks and abundant new bone apposition without inflammation or fibrous encapsulation.^{53,54,59} The above features make CPC extremely appealing for the treatment of recent thoracolumbar burst fractures in young people. In the setting of osteoporosis, early bioresorption of the cement may be a problem if it does not happen in parallel with new bone formation. Despite their favorable bioresorbable characteristics, CPCs have longer setting times at low temperatures (around 10 minutes), inferior strength compared with PMMA, and reduced cohesion because of their hydrophilic properties, which make them difficult to inject.⁵⁹ We would recommend using this type of cement after creating a cavity in the vertebral body, for example, with an expandable balloon like in kyphoplasty, to avoid separation of the aqueous solution and the crystal minerals during injection. For a more detailed analysis of the various cement types and their properties, the reader is urged to refer to <http://www.openradiology.org> and to the instructions for use of the various manufacturers.

Usually the patient needs conscious sedation during injection of cement, which is painful because of the PMMA exothermic reaction. Constant vigilance with continuous lateral and intermittent frontal fluoroscopy and undivided attention and scrutiny by the responsible practitioner are mandatory during cement injection to promptly identify any inadvertent leaks.^{3,4} The risk of cement leak is higher at the beginning of the injection, when the cement is most viscous. If a leak is identified after the first drops of cement, the injection pressure is immediately released, or even reversed.^{1,2,9} The injection may continue after a short interval of 30 to 60 seconds to allow the cement to harden and seal the leak. If the leak continues, then the needle must be slightly withdrawn and the bevel rotated to point the cement injection to a different direction. The injection must be immediately interrupted if the cement reaches the posterior vertebral cortex.^{1,2,9}

Usually, 2.5 to 4 mL of cement provides optimal vertebral filling in case of osteoporosis or hemangiomas, although in metastases, 1.5 to 2.5 mL suffices to alleviate pain and avoid complications.⁴ The suggested end point is cement packing of the anterior half to two-thirds of the vertebral body, with cement extending across the midline to the contralateral side of the vertebra (Fig. 1).^{1,37} If a fracture cleft is present, the operator should try to fill it with cement.¹ In case of a bipedicular approach, cement from the first injection might obscure visualization of the second injection. Maximal cement filling is not recommended because of the risk of cement overflow. After satisfactory filling and before hardening of the cement, the stylet needle has to be reinserted to evacuate the small volume of cement residing within the cannula's dead space. Otherwise, needle removal may be difficult, and there is the risk of cement leak along the needle tract. There are anecdotal cases of linear cement leaks through the pedicle reaching the skin surface that had to be removed surgically. In case the needle stylet

cannot be reinserted, continuous clockwise and counter-clockwise rotation of the cannula under fluoroscopy helps to detach the needle without cement leak.

After completion of the procedure and before removing the patient from the table, the operator should wait for cement hardening, as indicated by the setting of the rest of the cement in the mixing bowl.² In addition, the patient is allowed to ambulate at least 2 hours after the procedure (or even later if CPC was injected). Routine monitoring of vital signs and a neurological examination are recommended in the immediate post-procedural period. Nonsteroidal painkillers or steroid anti-inflammatory drugs may be prescribed for 2 to 4 days after PMMA cementoplasty.²

COMPLICATIONS

The likelihood of complications, especially cement leakage, is higher during treatment of metastatic lesions than of osteoporotic compression fractures; therefore, the risk-benefit ratio should be evaluated wisely, especially when deciding to perform cementoplasty in a patient with multilevel bone metastases. The recommended complication threshold for a specialized tertiary center performing percutaneous vertebroplasty and cementoplasty for pain management is 2% for osteoporotic indications and 10% for malignant cases.⁹

Although it is usually asymptomatic, inadvertent cement leak is the first and most fearsome complication of cementoplasty.^{1,60} Detection of cement leaks on follow-up radiographs ranges from 30 to 72.5% and reaches more than 90% on CT.^{1,61} During vertebroplasty, cement may leak toward the epidural veins or the epidural space, inside the neural foramina, toward the disk, the perivertebral venous plexus, or into the paravertebral soft tissues. Cement leaks tracking into the aorta and the intercostal arteries have also been described.^{1-4,37,60} Posterior cement overflow into the spinal

Figure 1 Percutaneous vertebroplasty of an L2 painful insufficiency fracture. (a) Baseline Short T1 Inversion Recovery (STIR) magnetic resonance imaging shows increased signal of the vertebral body, mainly near the superior end plate. (b) Transpedicular placement of a 10-gauge vertebroplasty needle in the anterior third of the vertebral body (lateral projection). (c) Final result after injection a 3.5 mL of polymethyl methacrylate. Note the symmetric deposition of cement across the midline (frontal projection).

canal and spinal cord compression constitute a major complication that may require urgent surgical decompression in case of paraplegia (Fig. 2). The reported rate of transient neurological deficits, which usually improve within 30 days from the intervention, is 1% in osteoporotic patients and 5% in patients with metastases.⁹ Cement leak into the neural foramina is less well tolerated because of the narrow intraforaminal space and may cause chemical and thermal damage of the exiting nerve, resulting in radiculopathy.⁴ If this happens, fluoroscopy-guided intraforaminal injection of normal saline, lidocaine, and steroids with a spinal needle should be performed immediately to cool the root and treat the inflammation.¹

Perivertebral venous leaks are of crucial importance because they may continue unidentified and cause cement pulmonary embolism.³ Cement pulmonary embolism is usually peripheral and asymptomatic and may occur in 4.0 to 6.8% of vertebroplasty cases.^{1,62–64} Paradoxical cerebral cement embolism has also been reported.⁶⁵ Intradiscal cement leaks usually affect the overlying intervertebral disk, and they may be associated with an increased risk of adjacent vertebral collapse because of the altered disk biomechanics.⁶⁶ Epidural vein fillings and paravertebral leaks into the soft tissues are usually asymptomatic without any clinical significance.^{3,4}

The second most worrisome complication is local infection, which occurs in less than 1% of cases.² Therefore, adherence to strict sterility protocols during all minimally invasive musculoskeletal interventions cannot be overstressed. Development of an epidural abscess requires surgical debridement and probably definite removal of the infected tissue and cement followed by spine stabilization.⁶⁷ Periprocedural fracture of the ribs,

the vertebral posterior elements, or the pedicle because of operator manipulations occurs in less than 1% of cases, and along with bleeding from the puncture site and local hematomas, they are considered minor complications.² After the procedure, patients may experience transient fever and localized pain because of the exothermic reaction of the acrylic glue. Postprocedural pain is proportional to the volume of cement injected. However, adequate pain relief is usually achieved within 24 hours.^{1,4} Last, the procedure entails some finite risks of allergy to acrylic cement and other filler materials. Systemic circulation of unreacted PMMA liquid monomer may also cause hypotension and arrhythmias.^{2,68} Practitioners should also be aware of airway reactions like coughing, bronchospasm, and occupational asthma after exposure to PMMA cement vapors, whose recorded levels are, however, very low during percutaneous cementoplasty.⁶⁹

To minimize the risk of complications and maximize clinical success, international guidelines recommend adequate training of the operator, availability of high-quality fluoroscopy, good patient selection, correct needle placement, and up to three to four vertebral levels per each cementoplasty procedure.^{2,9} Approximately 70% of cases with painful bone metastases, 80% of vertebral hemangiomas, and 90% of patients with osteoporotic fractures will experience satisfactory pain relief from the procedure with improved mobility and quality of life.^{2,4,6,14,21,70,71} However, recently published data from two randomized controlled trials showed no statistically significant superiority of vertebroplasty versus sham procedure in terms of pain relief^{72,73} and have spurred worldwide conflict and debate on their overall scientific merit because of their flawed design, unrealistic patient recruitment, and low

Figure 2 Cement leaks. (a) Epidural cement leak following lumbar vertebroplasty. There was cement overflow in close proximity to the spinal cord. The needle tract indicating an incorrect needle trajectory that breached the spinal canal is also evident. (b) Extensive cement leakage after lower lumbar kyphoplasty in another case. Note the incorrect needle pathway and the extensive cement leak across the canal. Remarkably, both cases were asymptomatic.

statistical power.⁷⁴⁻⁷⁶ Painful compression fractures older than 6 months may respond to cementoplasty but with lower rates of success.⁷⁷ After vertebroplasty, new compression fractures occur in up to a quarter of the patients, and almost half of those are located in levels adjacent to the treated ones, usually immediately cephalad.⁷⁸ Interestingly, one study reported repeat fractures of already treated vertebrae in 63% of the cases.⁷⁹ A recent systematic review concluded that there is no definite answer to whether vertebroplasty increases the risk of new fractures in patients with osteoporosis.⁸⁰

KYPHOPLASTY

Kyphoplasty was introduced in 2001. It is a modification of vertebroplasty, employing a balloon tamp to restore vertebral height and create a cavity inside the vertebral body to accommodate the implanted cement.⁸¹ The goal is to correct or prevent the kyphotic deformities after loss of vertebral height. However, the fundamental principle of both vertebroplasty and kyphoplasty remains mechanical bone stabilization with cement injection.^{82,83} The balloon tamp is advanced and inflated through an 8-gauge cannula inserted as in vertebroplasty. The main advocated advantage of kyphoplasty is restoration of vertebral body height, at the expense, however, of general anesthesia and up to 10 times higher procedural costs. The reported mean height restoration after kyphoplasty for compression fractures is around 3 to 5 mm at the center of the vertebral body.⁸⁴

Recent data from randomized controlled trials of vertebroplasty or kyphoplasty versus optimal medical therapy demonstrate that both procedures are significantly better in terms of pain relief and patient mobility.^{1,84-87} Notwithstanding the lack of head-to-head multicenter randomized trials between vertebroplasty and kyphoplasty, systematic analyses of the literature have shown that both procedures are equally effective in the pain management of osteoporotic compression fractures.^{84,86,88,89} Recently released data of a single-center randomized trial of vertebroplasty versus kyphoplasty with PMMA in 100 patients with osteoporotic fractures showed no significant difference in pain relief between the two techniques after 6 months.⁹⁰ However, it is claimed that kyphoplasty is associated with less than half the risk of cement leak compared with vertebroplasty.^{91,92} On the other hand, literature reviews report that there is no significant difference in vertebral height restoration between the two techniques.^{92,93} In addition, the unsubstantiated marketing allegation of lower leaks during kyphoplasty on the basis of low-pressure cement injection after creation of the cavity has been recently challenged.⁸⁴ Nonetheless, it is the authors' personal opinion that every practitioner should have adequate knowledge of the advantages and shortcomings of both

procedures and must be equally trained and skillful in executing each of them according to clinical circumstances.

OSTEOPLASTY AND BONE ABLATION

Cementoplasty of the sacrum (sacroplasty), the acetabulum (acetabuloplasty), and other weight-bearing bones (osteoplasty in general) are procedural variants of percutaneous vertebroplasty aiming to palliate pain by cement reinforcement of malignant osteolytic lesions. Effective management of painful insufficiency fractures or malignant osteolyses of the sacrum, the pubic rami, the ischial tuberosities, and the acetabulum may be achieved with image-guided injection of PMMA.^{18,19,94} The same principles apply for extraspinal cementoplasty or osteoplasty as in percutaneous vertebroplasty. CT guidance is advocated for acetabuloplasty, whereas a bull's-eye fluoroscopic approach may be employed for pubic osteoplasty. Injection of iodinated contrast before cementoplasty is advocated to predict distribution of cement and visualize potential pathways of cement extravasation. Potential complications include cement-induced injury of sensitive neurovascular structures like the obturator and the pudendal nerve.¹⁸ Therefore, familiarity with local anatomic details and relationships is critical. Intra-articular cement leak into the hip joint has also been reported without any clinical significance.^{18,19} Cementoplasty of osteolyses located in the diaphysis of long weight-bearing bones like the femur should be avoided, because of inadequate bone consolidation and pathological fractures. However, femoral head lesions have been successfully treated.¹⁹ Reported rates of pain relief after osteoplasty for extraspinal bone metastases are comparable to those of vertebroplasty.⁹⁴

In case of painful expansile osteolytic lesions of the pelvis, cementoplasty may be combined with modern cryo- or thermocoagulation techniques with the aim of palliative bone consolidation following tumor destruction.³⁰ In such cases, practitioners should be aware that PMMA setting times depend on local tissue temperature. Therefore, higher ambient temperatures, like after radiofrequency or microwave ablation, will accelerate polymerization and hardening of the material. On the contrary, lower temperatures, such as during subzero cryoablation, will significantly delay the reaction with increased risks of leak.³⁰ Hence, it is recommended that cementoplasty is delayed for 2 to 24 hours after the completion of the ablative sessions to allow for normalization of local tissue temperatures.

CONCLUSION

Percutaneous cementoplasty is a key element of modern pain management therapy for the treatment of osteoporotic insufficiency fractures and painful bone metastases.

Practitioners should evaluate each patient carefully and have a thorough knowledge of the anatomy and the various different techniques for image-guided lesion access and cement injection. Understanding of the particular advantages and limitations of the various modern filler materials is also crucial for a successful and uncomplicated procedure. Future developments include new mechanical devices for effective restoration of vertebral height, as well as the introduction of both osteoconductive and osteoinductive cements that will be able to promote more physiological bone healing.

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