American College of Radiology
ACR Appropriateness Criteria®

Management of Vertebral Compression Fractures

Variant: 1 New symptomatic vertebral compression fracture (VCF) identified on radiographs. No known malignancy. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
MRI spine area of interest without IV contrast	Usually Appropriate	O
CT spine area of interest without IV contrast	Usually Appropriate	Varies
Bone scan whole body	May Be Appropriate	☢☢☢
SPECT or SPECT/CT spine area of interest	May Be Appropriate	☢☢☢
CT spine area of interest with IV contrast	Usually Not Appropriate	Varies
CT spine area of interest without and with IV contrast	Usually Not Appropriate	Varies
MRI spine area of interest with IV contrast	Usually Not Appropriate	O
MRI spine area of interest without and with IV contrast	Usually Not Appropriate	O
CT myelography spine area of interest	Usually Not Appropriate	Varies
FDG-PET/CT skull base to mid-thigh	Usually Not Appropriate	☢☢☢☢

Variant: 2 New symptomatic VCF identified on radiographs. History of malignancy. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
MRI spine area of interest without and with IV contrast	Usually Appropriate	O
CT spine area of interest without IV contrast	Usually Appropriate	Varies
MRI spine area of interest without IV contrast	Usually Appropriate	O
FDG-PET/CT skull base to mid-thigh	May Be Appropriate	☢☢☢☢
Bone scan whole body	May Be Appropriate	☢☢☢
Image-guided biopsy spine area of interest	May Be Appropriate	Varies
MRI spine area of interest with IV contrast	May Be Appropriate (Disagreement)	O
SPECT or SPECT/CT spine area of interest	May Be Appropriate	☢☢☢
CT myelography spine area of interest	May Be Appropriate	Varies
CT spine area of interest with IV contrast	Usually Not Appropriate	Varies
CT spine area of interest without and with IV contrast	Usually Not Appropriate	Varies

Variant: 3 New back pain. Previously treated VCF or multiple VCFs. Initial Imaging.

Procedure	Appropriateness Category	Relative Radiation Level
CT spine area of interest without IV contrast	Usually Appropriate	Varies
MRI spine area of interest without IV contrast	Usually Appropriate	O
MRI spine area of interest without and with IV contrast	May Be Appropriate	O
Bone scan whole body	May Be Appropriate	☢☢☢
FDG-PET/CT skull base to mid-thigh	May Be Appropriate	☢☢☢☢
SPECT or SPECT/CT spine area of interest	May Be Appropriate	☢☢☢
CT myelography spine area of interest	Usually Not Appropriate	Varies
CT spine area of interest with IV contrast	Usually Not Appropriate	Varies

CT spine area of interest without and with IV contrast	Usually Not Appropriate	Varies
MRI spine area of interest with IV contrast	Usually Not Appropriate	O

Variant: 4 Asymptomatic VCF identified on radiographs. History of malignancy. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
MRI spine area of interest without and with IV contrast	Usually Appropriate	O
CT spine area of interest without IV contrast	Usually Appropriate	Varies
MRI spine area of interest without IV contrast	Usually Appropriate	O
Bone scan whole body	May Be Appropriate	☢☢☢
FDG-PET/CT skull base to mid-thigh	May Be Appropriate	☢☢☢☢
Image-guided biopsy spine area of interest	May Be Appropriate	Varies
SPECT or SPECT/CT spine area of interest	May Be Appropriate	☢☢☢
CT myelography spine area of interest	Usually Not Appropriate	Varies
CT spine area of interest with IV contrast	Usually Not Appropriate	Varies
CT spine area of interest without and with IV contrast	Usually Not Appropriate	Varies
MRI spine area of interest with IV contrast	Usually Not Appropriate	O

Variant: 5 Asymptomatic, osteoporotic VCF. Initial treatment.

Procedure	Appropriateness Category	Relative Radiation Level
Medical management only	Usually Appropriate	
Percutaneous vertebral augmentation	Usually Not Appropriate	
Surgical consultation	Usually Not Appropriate	
Percutaneous ablation spine	Usually Not Appropriate	
Radiation oncology consultation	Usually Not Appropriate	

Variant: 6 Symptomatic osteoporotic VCF with bone marrow edema or intravertebral cleft. Initial treatment.

Procedure	Appropriateness Category	Relative Radiation Level
Medical management only	Usually Appropriate	
Percutaneous vertebral augmentation	Usually Appropriate	
Surgical consultation	May Be Appropriate	
Percutaneous ablation spine	Usually Not Appropriate	
Radiation oncology consultation	Usually Not Appropriate	
Systemic radionuclide therapy	Usually Not Appropriate	

Variant: 7 New symptomatic VCF. History of prior vertebroplasty or surgery. Initial treatment.

Procedure	Appropriateness Category	Relative Radiation Level
Percutaneous vertebral augmentation	Usually Appropriate	
Medical management only	Usually Appropriate	
Surgical consultation	May Be Appropriate	
Percutaneous ablation spine	Usually Not Appropriate	
Radiation oncology consultation	Usually Not Appropriate	

Systemic radionuclide therapy	Usually Not Appropriate	

Variant: 8 Benign VCF with worsening pain, deformity, or pulmonary dysfunction. Initial treatment.

Procedure	Appropriateness Category	Relative Radiation Level
Percutaneous vertebral augmentation	Usually Appropriate	
Surgical consultation	Usually Appropriate	
Medical management only	May Be Appropriate	
Percutaneous ablation spine	Usually Not Appropriate	
Radiation oncology consultation	Usually Not Appropriate	
Systemic radionuclide therapy	Usually Not Appropriate	

Variant: 9 Pathological VCF with ongoing or increasing mechanical pain. Initial treatment.

Procedure	Appropriateness Category	Relative Radiation Level
Radiation oncology consultation	Usually Appropriate	
Surgical consultation	Usually Appropriate	
Percutaneous ablation spine	Usually Appropriate	
Percutaneous vertebral augmentation	Usually Appropriate	
Medical management only	May Be Appropriate	
Systemic radionuclide therapy	May Be Appropriate	

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Summary of Literature Review

Introduction/Background

Vertebral compression fractures (VCFs) can be caused by benign clinical conditions such as osteoporosis, metabolic disorders, congenital disorders, infections, and acute trauma or neoplasms. Neoplasms may incorporate primary/secondary bone tumors and myeloma. Painful VCFs may cause a marked decline in physical activity and quality of life, leading to general physical deconditioning with increased psychological distress. This physical deconditioning, in turn, may prompt further complications related to poor inspiratory effort (ie, atelectasis and pneumonia) [1] and venous stasis (ie, deep venous thrombosis and pulmonary embolism) [2]. Successful and timely management of painful VCFs can improve quality of life, increase the likelihood of an independent and productive life, and prevent superimposed medical complications.

This document addresses the management of both osteoporotic and pathologic VCFs.

Comprehensive medical management involves appropriate osteoporosis screening and follow-up treatment (see the ACR Appropriateness Criteria® topic on "Osteoporosis and Bone Mineral Density" [3]). The postmenopausal female population is most at risk for developing osteoporotic fractures of any type, and VCFs comprise 25% of osteoporotic fractures [4-6]. However, there is also an increased incidence of osteoporosis-related fragility fractures in males [7], with a lack of widespread awareness of the risk of osteoporosis in men currently comparable to that of osteoporosis in women 30 years ago [8]. In the setting of "red flags" (see Appendix 1), the initial evaluation of a painful VCF includes assessing any neurologic deficits and evaluating mechanical versus radicular pain. Subsequently, imaging of the affected spinal segment is performed to characterize the fracture and to determine the extent of disease. In a meta-analysis of more than 2 million patients, those with osteoporotic VCFs who underwent vertebral augmentation (VA) were 22% less likely to die at up to 10 years after treatment than those who received nonsurgical treatment [9]. Hirsch et al [10] analyzed the Medicare database for the number needed to treat to save one life at 1 year and up to 5 years after VA and showed that VA conferred a significant mortality benefit over nonsurgical management with the adjusted number needed to treat to save one life for nonsurgical management versus kyphoplasty ranged from 14.8 at year 1 to 11.9 at year 5. The adjusted number needed to treat for nonsurgical management versus vertebroplasty (VP) ranged from 22.8 at year 1 to 23.8 at year 5.

Neoplasms causing VCFs include 1) primary benign bone neoplasms, such as hemangioma (aggressive type) or giant cell tumors [11], and tumor-like conditions causing bony and cellular remodeling, such as aneurysmal bone cysts, or Paget disease (osteitis deformans); 2) primary malignant neoplasms including but not limited to multiple myeloma and lymphoma; and 3) metastatic neoplasms [2,12,13]. Because the literature has focused predominantly on VCFs due to metastatic disease, this document focuses on the management of pathological VCFs secondary to metastatic disease. However, it should be noted that treatment can vary depending on tumor type.

VCFs secondary to underlying malignant or metastatic disease can result in skeletal-related events, including bone pain, pathologic vertebral fractures, and epidural spinal cord compression. The pathologic vertebral fractures may also have associated mechanical instability. The Spine Oncology Study Group (SOSG) has developed the Spinal Instability Neoplastic Score (SINS) to evaluate spinal stability. One of the categories within SINS is the presence of a pathologic VCF. The rating is a composite of clinical and radiographic data, including location, pain, bone quality, alignment, vertebral body collapse, and posterolateral involvement. The affected spinal segment can be classified as stable (0–6), potentially unstable (7–12), and unstable (13–18). The SINS is routinely used by oncologic spine surgeons and spine radiation oncologists and has excellent interobserver and intraobserver reliability [14]. SINS has also been shown in clinical studies to be a tool enabling the prediction of VCF or the progression of an existing VCF postradiation [15]. A radiographic grading system for metastatic epidural spinal cord compression developed by the SOSG can also be used to guide management [16].

Special Treatment Considerations

VA is a generic term that includes percutaneous VP, balloon-assisted kyphoplasty (BK) [2], and other implantable methods of VA [17-20]. These procedures, the majority of which are described in the lumbar and thoracic spine, are used for the palliation of pain related to VCFs and have been shown to be effective compared to medical management [13,21-23].

Many studies have compared VP to BK [24-30] and the appropriate timing of VA [21-23,31-34]. A thorough description of the indications and contraindications to VA is detailed in the ACR–ASNR–ASSR–SIR–SNIS Practice Parameter for the Performance of Vertebral Augmentation [35]. Because the clinical outcome studies show essentially the same benefit of BK as VP for patient pain relief and mobility and similar complication rates, a multisociety panel of spine interventionalist holds the position that BK or VP may be considered to be useful and generally interchangeable techniques for the performance of VA. The panel recognizes that selection of VP or BK may be related to additional factors, such as the degree of compression deformity, the age of fracture, and the presence of neoplastic involvement [36].

Minimally invasive percutaneous image-guided techniques for treating spine tumors include newer technologies, such as radiofrequency ablation (RFA) [37], cryoablation, microwave ablation, alcohol ablation, and laser photocoagulation. These modalities provide an alternative or adjunct therapeutic option for treating spinal tumors beyond medical pain management, surgery, radiation therapy (RT), and standard VA. Curative ablation can be applied to treat specific benign or selected cases of malignant oligometastatic spinal tumors. Pain palliation of primary and secondary bone tumors is also possible with ablation (chemical, thermal, mechanical), cavitation (radiofrequency ionization), and consolidation (VP, BK) techniques performed separately or in combination.

Discussion of Procedures by Variant

Variant 1: New symptomatic vertebral compression fracture (VCF) identified on radiographs. No known malignancy. Next imaging study.

The body regions covered in this clinical scenario are the cervical, thoracic, and lumbar spine. These body regions might be evaluated separately or in combination as guided by physical examination findings, patient history, and other available information, including prior imaging.

For some authors, focal tenderness upon palpation in correlation with radiographs of the vertebral column is a satisfactory indication for intervention. However, spine radiographs are often nonspecific with respect to the acuity or cause of the vertebral fracture [38].

Variant 1: New symptomatic vertebral compression fracture (VCF) identified on radiographs. No known malignancy. Next imaging study.
A. CT Spine Area of Interest

CT provides osseous details of axial spine fractures before VA [12,39]. CT permits evaluation of vertebral body height, architecture, and integrity of the posterior cortex and pedicles before VA, which is critical in patients with cortical disruption, posterior cortex osseous retropulsion, and spinal canal compression. Comparison to prior imaging is helpful to determine acuity. Dual-energy CT may show bone marrow edema with reasonably high sensitivity and specificity [40,41] and good concordance to MRI in thoracolumbar VCFs [42]. Intravenous (IV) contrast does not provide additional value in this clinical scenario.

Variant 1: New symptomatic vertebral compression fracture (VCF) identified on radiographs. No known malignancy. Next imaging study.
B. CT Myelography Spine Area of Interest

CT myelography is not routinely used for evaluating benign VCFs unless the patient has a neurologic deficit with suspected spinal canal compression.

Variant 1: New symptomatic vertebral compression fracture (VCF) identified on radiographs.

No known malignancy. Next imaging study.

C. MRI Spine Area of Interest

MRI may provide valuable information to determine the need for intervention and procedural guidance. The benefits of MRI for preprocedural planning have been reported [43-45]. Minimally deforming fractures that may not be well seen on conventional radiographs may be better detected on preprocedure MRI, mainly if the imaging evaluation is >3 months since the suspected injury or if there is a change in symptoms from the initial workup [43,46]. Fluid-sensitive MRI sequences (short tau inversion recovery or fat-saturated T2-weighted imaging) help detect and differentiate acute/subacute versus chronic fractures, identifying fracture clefts, and differentiating synchronous fractures [46,47]. MRI is also valuable for distinguishing recent from chronic vertebral fractures in patients with multiple vertebral fractures and diffuse back pain, which can at times confound the clinical examination [48,49]. However, vertebral body edema is not a precise measure of compression fracture age because the duration after an osteoporotic compression fracture is often not known with certainty. Bone marrow edema typically resolves within 1 to 3 months [50,51]. IV contrast is not useful because it does not add information in the setting of recent osteoporotic VCF.

Variant 1: New symptomatic vertebral compression fracture (VCF) identified on radiographs. No known malignancy. Next imaging study.

D. Bone Scan Whole Body

Tc-99m whole-body bone scan (bone scintigraphy) may be helpful to determine the painful vertebrae [52], particularly the causative level [53,54]. Bone scan and MRI have higher concordance with single-level fractures compared with multiple level involvements [55]. When more than one area of increased activity is detected, bone scans may overestimate the number of acute fractures. As such, multiple regions of radiotracer accumulation should be interpreted cautiously [56]. The utilization of bone scans may be based on institutional preference.

Variant 1: New symptomatic vertebral compression fracture (VCF) identified on radiographs. No known malignancy. Next imaging study.

E. SPECT or SPECT/CT Spine Area of Interest

Single-photon emission computed tomography (SPECT) coupled with CT provides complementary information because sites of abnormal radiopharmaceutical uptake on the spine are of interest. SPECT images can be anatomically localized on the CT, and anatomic abnormalities on CT images can draw attention to subtle areas of SPECT tracer uptake. SPECT/CT has been shown to localize abnormalities in the vertebra more precisely compared with SPECT imaging alone, particularly in complicated cases, such as multiple collapsed vertebrae of different ages [57]. Studies have demonstrated a 63% to 80% agreement between SPECT/CT and MRI in detecting acute VCF [58,59]. Li et al [60] found that SPECT/CT is useful for imaging diagnosis of acute fractures in their study of 46 patients.

Variant 1: New symptomatic vertebral compression fracture (VCF) identified on radiographs. No known malignancy. Next imaging study.

F. FDG-PET/CT Skull Base to Mid-Thigh

PET using the tracer fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG) combined with morphologic CT imaging can noninvasively localize metabolic activity in areas of spinal infection [61-63]. Vertebral osteomyelitis may present as a compression fracture [64] and may be difficult to distinguish from noninfectious, osteoporotic VCF. Vertebral osteomyelitis may be considered in the setting of severe back pain, persistent unexplained fever, elevated inflammatory markers (ie,

erythrocyte sedimentation rate), or bacteremia without a known extravertebral focus of infection, particularly if the patient is immunocompromised. Importantly, acute benign VCFs can be a source of false positive findings due to increased FDG uptake in the acute phase; however, the increased activity should return to normal in 3 months from the fracture date. If there is a failure of increased PET FDG activity in a VCF to return to normal by 3 months, clinical suspicion for malignancy or infection should remain high [65].

Variant 2: New symptomatic VCF identified on radiographs. History of malignancy. Next imaging study.

The body regions covered in this clinical scenario are the cervical, thoracic, and lumbar spine. These body regions might be evaluated separately or in combination, guided by physical examination findings, patient history, and other available information, including prior imaging.

For some authors, focal tenderness upon palpation in correlation with radiographs of the vertebral column is a satisfactory indication for intervention. However, spine radiographs are often nonspecific with respect to the acuity or cause of the vertebral fracture [38].

Variant 2: New symptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
A. CT Spine Area of Interest

CT provides osseous details of axial spine fractures before VA [12,39]. CT permits evaluation of vertebral body height, architecture, and integrity of the posterior cortex and pedicles before VA, which is critical in patients with cortical disruption, posterior cortex osseous retropulsion, epidural extension, and spinal canal compression. Comparison to prior imaging is helpful to determine acuity. The presence of lobulated paraspinal masses with involvement of both vertebral body and posterior elements at the same time favors malignant involvement [66]. Dual-energy CT may show bone marrow edema with reasonably high sensitivity and specificity [40,41] and good concordance to MRI in thoracolumbar VCFs [42]. The presence of intravertebral vacuum phenomenon favors a benign etiology [67]. IV contrast does not provide additional value in this clinical scenario.

Variant 2: New symptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
B. CT Myelography Spine Area of Interest

CT myelography of the spine may be useful in patients in this clinical scenario because it can delineate the degree of thecal sac compression. Myelography is also obtained in patients with previous metal hardware to evaluate epidural disease and to accurately delineate the spinal cord for preirradiation treatment planning.

Variant 2: New symptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
C. MRI Spine Area of Interest

MRI may provide valuable information to differentiate malignant from benign VCFs. Neoplastic VCFs often have a total replacement of the normally high T1 bone marrow signal intensity, resulting in diffuse homogeneous low signal intensity. In osteoporosis, the underlying mechanism leading to fracture is the loss of bone mineral density with preservation of the marrow [68]. Abnormal marrow signal involving the pedicles or other posterior elements is a strong indicator of malignancy in VCFs because tumor spread to the posterior elements typically occurs before tumor-associated structural instability leads to fracture within the vertebral body [65,69]. Although

osteoporotic fractures can also have edema in the pedicles related to stress reaction, they infrequently have signal change in the posterior elements [65,69]. Abnormal epidural or paravertebral soft tissue is another imaging finding suggesting a pathologic VCF with convex retropulsion of the posterior cortex [70]. A bilobed appearance in the ventral extradural space is more commonly seen in neoplastic disease, as opposed to nonneoplastic disease, in which there is preservation of the strong attachment of the central sagittal septum [71]. Fluid-sensitive MRI sequences (short tau inversion recovery or fat-saturated T2-weighted imaging) can help detect fracture clefts and identify synchronous fractures [46,47]. IV contrast may yield beneficial information with increased homogenous and heterogenous enhancement patterns seen more in neoplastic fractures with or without associated enhancing paraspinal soft tissues. Enhancement involving the posterior elements raises the suspicion for malignancy further [66]. Diffusion and perfusion imaging are also used to help differentiate benign from malignant compression fractures with low apparent diffusion coefficient values and increased perfusion parameters, suggesting neoplastic over benign involvement [66].

Variant 2: New symptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
D. Bone Scan Whole Body

Tc-99m whole-body bone scan (bone scintigraphy) may be helpful to determine the painful vertebrae [52] and also to evaluate other areas of metastases because of complete skeletal coverage, especially in a patient with a history of malignancy [53,54,58]. Bone scan and MRI have higher concordance with single-level fractures compared with multiple-level involvement [55]. When more than one area of increased activity is detected, bone scans may overestimate the number of acute fractures. As such, multiple regions of radiotracer accumulation should be interpreted cautiously [56]. Osteosclerotic bone metastases can be detected on bone scintigraphy up to 18 months earlier than on radiographs [72]. The utilization of bone scans may be based on institutional preference.

Variant 2: New symptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
E. SPECT or SPECT/CT Spine Area of Interest

SPECT coupled with CT provides complementary information because sites of abnormal radiopharmaceutical uptake on the spine are of interest. SPECT images can be anatomically localized on the CT, and anatomic abnormalities on CT images can draw attention to subtle areas of SPECT tracer uptake. SPECT/CT has been shown to localize abnormalities in the vertebra more precisely compared to SPECT imaging alone, particularly in complicated cases, such as multiple collapsed vertebrae of different ages [57]. Studies have demonstrated a 63% to 80% agreement between SPECT/CT and MRI in detecting acute VCF [58,59]. Bone SPECT/CT can also gauge successful treatment response after VA and adds valuable information for the cause of back pain. [59].

Variant 2: New symptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
F. FDG-PET/CT Skull Base to Mid-Thigh

FDG-PET combined with morphologic CT imaging can noninvasively localize metabolic activity in areas of spinal neoplastic involvement and can differentiate between benign and malignant VCFs, with the caveat that acute osteoporotic fractures can also have a high standardized uptake value on PET/CT imaging. A meta-analysis by Kim et al [73] showed high sensitivity and moderate

specificity for the use of FDG-PET/CT to differentiate benign from malignant compression fractures. In a patient with a history of malignancy, PET/CT is routinely included in the paradigm of metastatic disease evaluation workup [61]. Vertebral osteomyelitis may present as a compression fracture [64] and may be difficult to distinguish from noninfectious, osteoporotic VCF. Other potential radiotracers have been described for the early detection of marrow-based metastases, such as ^{18}F-NaF PET/CT, which indicates areas of increased bone turnover and is generally used in the assessment of primary and secondary osseous malignancies, the evaluation of response to treatment, and the clarification of abnormalities on other imaging modalities or clinical data. However, ^{18}F-NaF PET/CT is a highly sensitive method in evaluating bone metastases (eg, prostate cancer). Still, it can be problematic because of low specificity because the tracer accumulates in degenerative and inflammatory bone diseases. ^{18}F-fluorocholine may be able to differentiate between degenerative and malignant osseous abnormalities because degenerative changes are not choline-avid [74]. Prostate-specific membrane antigen (PSMA)-PET imaging has been approved by the FDA in patients with prostate cancer with radioactive agent binding to prostatic cancer cells.

Variant 2: New symptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
G. Image-Guided Biopsy Spine Area of Interest

Percutaneous biopsy is performed to verify the etiology of VCF, especially if imaging findings are equivocal or the fractured vertebra is the only site of involvement in a patient with known malignancy. Biopsy has been shown to confirm clinical suspicion of neoplastic involvement and also aids in directing future treatment planning [75].

Variant 3: New back pain. Previously treated VCF or multiple VCFs. Initial Imaging.

The body regions covered in this clinical scenario are the cervical, thoracic, and lumbar spine. These body regions might be evaluated separately or in combination, guided by physical examination findings, patient history, and other available information, including prior imaging.

Variant 3: New back pain. Previously treated VCF or multiple VCFs. Initial Imaging.
A. CT Spine Area of Interest

CT provides osseous details of axial spine fractures prior to VA [12,39]. CT permits evaluation of vertebral body height, architecture, and integrity of the posterior cortex and pedicles before VA, which is critical in patients with cortical disruption, posterior cortex osseous retropulsion, epidural extension, and spinal canal compression. CT is also the optimal modality to identify cement leakage in paraspinal, epidural, intravascular, or adjacent discal regions [76,77]. CT also depicts the development of adjacent level fracture in a patient with recent augmentation and new back pain [78]. CT is also useful to evaluate the cause of new pain in patients with surgical intervention with hardware placement. This modality can evaluate a patient with new back pain after undergoing treatment of single- or multiple-level VCFs.

Variant 3: New back pain. Previously treated VCF or multiple VCFs. Initial Imaging.
B. CT Myelography Spine Area of Interest

CT myelography is not routinely used for evaluating benign VCFs unless the patient has a neurologic deficit with suspected spinal canal compression. This modality can also be helpful in patients who have surgical hardware from prior spinal surgical intervention to evaluate the spinal canal at the involved level.

Variant 3: New back pain. Previously treated VCF or multiple VCFs. Initial Imaging.

C. MRI Spine Area of Interest

Fluid-sensitive MRI sequences (short tau inversion recovery or fat-saturated T2-weighted imaging) help detect new acute adjacent level fractures after VCF treatment. MRI can also show the presence of procedure-related complications that can result in new pain in a treated patient, including epidural or paraspinal hematomas, infection in or around the treated level(s), spinal canal compression, and cord injury/ischemia [79]. A cerebrospinal fluid leak or pseudomeningocele formation is also well depicted with MRI [80]. IV contrast can add information in a posttreatment scan, especially to evaluate for any infection/inflammation in or adjacent to the spinal canal but it should be noted that sometimes a rind of enhancement maybe seen around the bone cement in treated vertebra due to reactionary changes and mild inflammatory response induced by polymethylmethacrylate.

Variant 3: New back pain. Previously treated VCF or multiple VCFs. Initial Imaging.
D. Bone Scan Whole Body

Tc-99m whole-body bone scan (bone scintigraphy) may be helpful to determine the painful vertebrae [52], particularly the causative level [53,54]. Bone scan and MRI have higher concordance with single-level fractures compared with multiple-level involvement [55]. When more than one area of increased activity is detected, bone scans may overestimate the number of acute fractures. As such, multiple regions of radiotracer accumulation should be interpreted cautiously [56]. The utilization of bone scans may be based on institutional preference.

Variant 3: New back pain. Previously treated VCF or multiple VCFs. Initial Imaging.
E. SPECT or SPECT/CT Spine Area of Interest

SPECT coupled with CT provides complementary information because sites of abnormal radiopharmaceutical uptake on the spine are of interest. SPECT images can be anatomically localized on the CT, and anatomic abnormalities on CT images can draw attention to subtle areas of SPECT tracer uptake. SPECT/CT has been shown to localize abnormalities in the vertebra more precisely compared with SPECT imaging alone, particularly in complicated cases, such as multiple collapsed vertebrae of different ages [57]. Studies have demonstrated a 63% to 80% agreement between SPECT/CT and MRI in detecting acute VCF [58,59]. SPECT/CT may be useful for imaging diagnosis of acute fractures [60].

Variant 3: New back pain. Previously treated VCF or multiple VCFs. Initial Imaging.
F. FDG-PET/CT Skull Base to Mid-Thigh

In the postprocedure setting, new pain may be due to infection. FDG-PET combined with morphologic CT imaging can noninvasively localize metabolic activity in areas of spinal infection. Studies on the diagnosis of vertebral osteomyelitis reported a sensitivity and specificity of 83% and 88% for FDG-PET/CT [61-63]. Vertebral osteomyelitis may present as a compression fracture [64] and may be difficult to distinguish from noninfectious, osteoporotic VCF. Vertebral osteomyelitis may be considered in the setting of severe back pain, persistent unexplained fever, elevated inflammatory markers (ie, erythrocyte sedimentation rate), or bacteremia without a known extravertebral focus of infection, particularly if the patient is immunocompromised.

Variant 4: Asymptomatic VCF identified on radiographs. History of malignancy. Next imaging study.

The body regions covered in this clinical scenario are the cervical, thoracic, and lumbar spine. These body regions might be evaluated separately or in combination, guided by physical examination findings, patient history, and other available information, including prior imaging.

Algorithms for patient selection and VCF management have been proposed by multidisciplinary groups that include oncology, surgery, and interventional radiology, based on evidence and expert opinion for managing metastatic spinal disease [81]. Medical therapy, including bisphosphonates for osteoclast inhibition [82-84] and osteoclast regulating agents [85-87], can be used to prevent skeletal-related events.

The SOSG has developed the SINS to evaluate spinal stability in patients with metastatic spinal disease, and the presence of VCF is within the SINS classification system. The rating is a composite of clinical and radiographic data that include location, pain, bone quality, alignment, presence and degree of VCF, and posterolateral involvement. The affected spinal segment can be classified as stable (0–6), potentially unstable (7–12), and unstable (13–18). The SINS is routinely used by oncologic spine surgeons and spine radiation oncologists and has excellent interobserver and intraobserver reliability [14]. A radiographic grading system for metastatic epidural spinal cord compression developed by the SOSG can also be used to guide management [16].

Variant 4: Asymptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
A. CT Spine Area of Interest

CT provides osseous details of axial spine fractures before VA [12,39]. CT permits evaluation of vertebral body height, architecture, and integrity of the posterior cortex and pedicles before VA, which is critical in patients with cortical disruption, posterior cortex osseous retropulsion, epidural extension, and spinal canal compression [12,39]. Comparison to prior imaging is helpful to determine acuity. The presence of lobulated paraspinal masses with involvement of both vertebral body and posterior elements at the same time favors malignant involvement [66]. CT is fast and can be used to evaluate a patient with new back pain after undergoing single- or multiple-level VCFs. Dual-energy CT may show bone marrow edema with reasonably high sensitivity and specificity [40,41] and good concordance to MRI in thoracolumbar VCFs [42]. Performing contrast-enhanced CT does not add much to the information already available.

Variant 4: Asymptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
B. MRI Spine Area of Interest

MRI can provide valuable information in the assessment of VCFs in patients with a history of malignancy or atypical clinical features. In addition to detecting metastases localized entirely in the bone marrow cavity, MRI can be used to differentiate benign from malignant fractures, because osteoporotic VCFs can occur in patients with malignancy [66,67,70,88,89]. MRI allows assessment of the degree of thecal sac or spinal cord compression, epidural tumor extension [16], paraspinal tumor extension, presence of other lesions, and lesion vascularity. Intraosseous disease is best delineated on noncontrast MRI sequences (T1-weighted and short tau inversion recovery). Contrast-enhanced MRI is helpful to delineate epidural, foraminal, paraspinal, and intrathecal disease extension, including intramedullary disease, compared to sequences without contrast. It is most beneficial to compare precontrast and postcontrast MRI sequences. With tumor involvement, marrow edema may be difficult to detect on conventional MRI sequences [90]. Diffusion-weighted [88] and MR perfusion techniques [91] may be helpful tools to differentiate benign from pathological fractures and new metastasis from previously treated lesions despite a similar appearance on conventional MRI [92]. MRI is also important for further treatment planning, such as VA, percutaneous ablation, RT (stereotactic body RT [SBRT] or conventional palliative radiation), or

systemic chemotherapy [93-96].

Variant 4: Asymptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
C. CT Myelography Spine Area of Interest

Myelography of the spine may be obtained especially to detect epidural tumor extension and spinal cord compression. This modality can also be helpful in patients who have surgical hardware from prior spinal surgical intervention to evaluate the spinal canal at the involved level.

Variant 4: Asymptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
D. Bone Scan Whole Body

Tc-99m bone scan (bone scintigraphy) of the whole body is often used for initial detection of metastases as well as the staging of patients with cancer. Hot uptake on a bone scan can persist for 2 years after the fracture [97] and hence is hard to differentiate a subacute from chronic fracture. In patients with osteoporosis, bone scan can show additional fractures in the skeleton and also can be helpful in distinguishing the cause of back pain among fracture, facet joint arthritis, and disc degenerative lesions and can be of help to triage appropriate treatment [98]. Bone scans may be performed based on institutional preference.

Variant 4: Asymptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
E. SPECT or SPECT/CT Spine Area of Interest

SPECT/CT has been shown to precisely localize abnormalities in the vertebra, particularly in complicated cases, such as multiple collapsed vertebrae of different ages [57]. However, MRI has a greater sensitivity and specificity for metastasis in specific spine locations [99] and for certain primaries, such as prostate cancer [100].

Variant 4: Asymptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
F. FDG-PET/CT Skull Base to Mid-Thigh

FDG-PET/CT may demonstrate localized metabolic activity in a neoplastic VCF and in areas of spinal infection [61-63]. MRI features coupled with clinical symptoms may help discern the etiology of a VCF with increased FDG uptake [101]. A meta-analysis study showed high sensitivity and moderate specificity for FDG-PET/CT to differentiate malignant versus benign VCFs [73]. Other potential radiotracers have been described for the early detection of marrow-based metastases, such as ^{18}F-NaF PET/CT, which indicates areas of increased bone turnover and is generally used in the assessment of primary and secondary osseous malignancies, the evaluation of response to treatment, and the clarification of abnormalities on other imaging modalities or clinical data. However, ^{18}F-NaF PET/CT is a highly sensitive method in evaluating bone metastases (eg, prostate cancer). Still, it can be problematic because of low specificity because the tracer accumulates in degenerative and inflammatory bone diseases. ^{18}F-fluorocholine may be able to differentiate between degenerative and malignant osseous abnormalities because degenerative changes are not choline-avid [74].

Variant 4: Asymptomatic VCF identified on radiographs. History of malignancy. Next imaging study.
G. Image-Guided Biopsy Spine Area of Interest

If the imaging features are ambiguous and not definitely in keeping with a pathologic VCF, a

biopsy can be performed to verify the etiology. A biopsy of the spine region of interest may be important for staging when isolated spine involvement is the first presentation of metastatic disease. Both fluoroscopy- and CT-guided spine biopsies can be performed with high diagnostic accuracy and few complications [102].

Variant 5: Asymptomatic, osteoporotic VCF. Initial treatment.

Most patients with VCFs have a gradual improvement in pain over 2 to 12 weeks, with a variable return of function [103,104]. Bone marrow edema associated with acute fractures on MRI typically resolves within 1 to 3 months [50,51].

Because conservative medical treatment does not prevent further collapse and does not prevent kyphosis, the timing of intervention has been an issue of debate. The VERTOS II trial, a randomized control trial comparing VA with medical management, revealed that 40% of conservatively treated patients had no significant pain relief after 1 year despite higher class prescription medication [34]. Approximately 1 in 5 patients with osteoporotic VCFs will develop chronic back pain as a result of the fracture [105,106]. Additionally, spinal deformity associated with VCF can contribute to impaired mobility and physical functioning. Spinal deformity may be defined as ≥15% kyphosis, ≥10% scoliosis, ≥10% dorsal wall height reduction, or vertebral body height loss ≥20% [107].

Patients may not be candidates for percutaneous or surgical intervention because of factors related to performance status, pregnancy, infection, or coagulation disorders, among others. Clinical decision-making must account for the overall risk and benefit to the patient.

Variant 5: Asymptomatic, osteoporotic VCF. Initial treatment.
A. Medical Management Only

Medical management is complementary to other therapies and should be offered in all clinical scenarios. The natural history of most healing VCFs is that of gradual improvement in pain over 2 to 12 weeks, with a variable return of function [103,104]. Conservative management includes medical management with or without methods of immobility and is the initial treatment of painful VCFs [36,107,108].

Asymptomatic osteoporotic VCFs do not require active management if not associated with focal mechanical pain and if there is no restriction of physical activity due to the fracture. Patients should return for a follow-up evaluation after 2 to 4 weeks of nonsurgical management, and, after a satisfactory result, continued follow-up may be unnecessary. Additional imaging and clinical assessment may be obtained for patients who have recurrence or persistence of symptoms to determine the source of their discomfort. There should be continuous evaluation and treatment for the underlying disorder of osteoporosis to prevent future fractures. Concerning follow-up, most currently available guidelines are restricted to recommendations on pharmacologic treatment for osteoporosis [109].

Physical therapy is likely to be useful in patients with VCFs and osteoporosis. Home exercise programs have a more limited evidence base, with some small trials demonstrating pain reduction, improved balance, and improved quality of life. Back extensor strengthening can improve strength and bone density and reduce the risk of future VCFs. Exercise is beneficial for all patients with osteoporosis [110,111].

Variant 5: Asymptomatic, osteoporotic VCF. Initial treatment.
B. Percutaneous Vertebral Augmentation

VA is not useful for compression fractures without clinical symptomatology such as mechanical pain or restricted physical activity appropriate for the patient's age. Clinical and imaging follow-up should be obtained in such patients, especially if there is new or a recurrence of pain or development of physical spinal deformity, to triage patients for future interventions if needed.

Variant 5: Asymptomatic, osteoporotic VCF. Initial treatment.
C. Percutaneous Ablation Spine

Percutaneous thermal ablation procedures are reserved for symptomatic spinal metastatic disease [112].

Variant 5: Asymptomatic, osteoporotic VCF. Initial treatment.
D. Surgical Consultation

Surgical intervention is reserved for patients with neurologic deficits, spinal deformity (eg, junctional kyphosis, retropulsion), or spinal instability. Surgical consultation can assist in prescribing and supervising immobilization devices.

Variant 5: Asymptomatic, osteoporotic VCF. Initial treatment.
E. Radiation Oncology Consultation

There is no role for RT in a patient without a cancer diagnosis and a nonpathologic VCF. If cancer is thought to be the cause of a VCF, a biopsy is needed to confirm a cancer diagnosis. RT is reserved for metastatic spinal disease and typically for those spinal metastases causing pain, neurologic compromise, or those asymptomatic lesions with radiologic features suggesting a risk of neurologic compromise or VCF.

Variant 6: Symptomatic osteoporotic VCF with bone marrow edema or intravertebral cleft. Initial treatment.

Variant 6: Symptomatic osteoporotic VCF with bone marrow edema or intravertebral cleft. Initial treatment.
A. Medical Management Only

The traditional first-line treatment of painful VCFs has been nonoperative or conservative management [107,108]. Conservative management includes a short period of bed rest followed by gradual mobilization with external orthoses. Because VCFs are flexion-compression injuries, a hyperextension brace is used. These braces may be beneficial for the first few months until the pain resolves [101]. Although younger patients may tolerate bracing well, elderly patients generally do not because of increased pain with bracing, leading to limited activity with more bed rest. Immobility predisposes patients to venous thrombosis and life-threatening complications such as pulmonary embolism [101]. It can also lead to pressure ulcers, pulmonary complications, urinary tract infections, and progressive deconditioning. Medical management is often complementary to other treatment strategies. To reduce pain and thus promote early mobilization with conservative management, appropriate analgesics should be prescribed. Narcotics should be reserved for patients who receive inadequate relief from regular analgesics and have to be used with caution given the associated effects of sedation, nausea, further decrease in physical conditioning, and fall risks. Most patients with osteoporotic VCF have spontaneous resolution of pain, even without medication, in 6 to 8 weeks [103,104,108,113]. Prevention and treatment of osteoporosis are one of the first steps in managing VCFs. Cigarette smoking should be discouraged, and alcohol should only be consumed in moderation. A daily weight-bearing exercise program should be recommended [101].

Patients may not be candidates for percutaneous or surgical intervention because of factors related to performance status, pregnancy, infection, or coagulation disorders, among others. Clinical decision-making must account for the overall risk and benefit to the patient.

Variant 6: Symptomatic osteoporotic VCF with bone marrow edema or intravertebral cleft. Initial treatment.

B. Percutaneous Vertebral Augmentation

VA, in the form of VP and BK, may be offered to patients who have failed conservative therapy for 3 months [34]. However, recent studies have found VA superior to placebo intervention for pain reduction in patients with acute osteoporotic VCF of <6 weeks duration [22].

Two randomized controlled trials that reported no statistically significant advantage for VA versus sham therapy raised discussions and controversial editorials, particularly regarding the inclusion criteria and other methodological issues [113,114]. Several studies have shown the benefit of VA versus conservative treatment in acute osteoporotic VCF [23,108,115-117], with benefits persisting through 1 year after intervention. However, others demonstrated that VA procedures might not affect global spinal alignment [118]. A meta-analysis found improvements in pain intensity, vertebral height, sagittal alignment, functional capacity, and quality of life with BK compared with conventional medical management [119]. Multiple other studies demonstrated the benefit of VA for alignment with improvement in pain relief [22,120-122] and respiratory function [89,123,124]. In a multisociety position statement, it was concluded that the VA of osteoporotic VCF is clearly beneficial in the short term and is likely beneficial in the long term [36]. Given the evidence that VA is more effective than prolonged medical treatment in achieving analgesia, improving function in patients with painful VCFs [117,125], and avoiding the complications of narcotic use, the threshold for performing VA has declined. Farrokhi et al [23] showed in a randomized control trial of percutaneous augmentation versus medical management for relief of pain and disability that the VA group had statistically significant improvements in pain and disability scores maintained over 24 months, improved vertebral body height restoration maintained over 36 months, and fewer adjacent level fractures compared to the medical management group.

The timing of when VA is useful has been debated. Studies found VA to be superior to placebo intervention for pain reduction in patients with acute osteoporotic VCF of <6 weeks duration [22]. In a study by Syed et al [33], patients with VCFs >12 weeks compared to those patients with VCFs <12 weeks had equivalent benefit, suggesting that the age of the fracture does not independently affect the outcomes of VA. However, Chen et al [21] showed improved pain relief in chronic fractures >3 months treated with VA compared to conservative management at 1 year follow-up.

Implant kyphoplasty is being performed more after the Sakos Trial findings supported the use of titanium implantable VA devices as an early treatment option for painful, acute VCFs with excellent risk/benefit profile [126]. Tutton et al [20] in the KAST study (The Kiva safety and effectiveness Trial), a multicentered randomized control trial successfully established that the Kiva system is noninferior to BK based on a composite primary endpoint assessment incorporating pain-, function-, and device-related serious adverse events for the treatment of osteoporotic VCFs.

Cianfoni et al [127] demonstrated the use of stent-assisted internal fixation as a minimally invasive option to obtain VA and restore axial load capability in severe osteoporotic fractures, potentially obviating more invasive surgical interventions in situations that would pose significant challenges to standard VA.

When the etiology of the VCF is questionable, biopsy may be necessary and can be performed as a part of the VA procedure [128,129].

Variant 6: Symptomatic osteoporotic VCF with bone marrow edema or intravertebral cleft. Initial treatment.
C. Percutaneous Ablation Spine

Percutaneous thermal ablation procedures are reserved for symptomatic spinal metastatic disease [112].

Variant 6: Symptomatic osteoporotic VCF with bone marrow edema or intravertebral cleft. Initial treatment.
D. Surgical Consultation

Surgical intervention is reserved for patients with neurologic deficits, spinal deformity (eg, junctional kyphosis, retropulsion), or spinal instability. Several surgical techniques have been developed to treat osteoporosis-related deformities, including posterior instrumentation with fusion. However, achieving fixation and fusion in these patients can be difficult secondary to insufficient bone integrity. Augmentation methods to improve pedicle screw fixation have evolved, including instrumentation at multiple levels, bioactive cement augmentation, and fenestrated or expandable pedicle screws, but their impact on clinical outcomes remains unknown. Management of osteoporosis in patients undergoing spine surgery is challenging. Still, with appropriate patient selection, medical optimization, and surgical techniques, these patients can experience pain relief, deformity correction, and improved function [130]. Surgical consultation can assist in prescribing and supervising immobilization devices.

When the etiology of the VCF is questionable and not amenable to percutaneous biopsy, an open biopsy may be necessary.

Variant 6: Symptomatic osteoporotic VCF with bone marrow edema or intravertebral cleft. Initial treatment.
E. Radiation Oncology Consultation

There is no role for RT in a patient without a cancer diagnosis and a nonpathologic VCF. If cancer is thought to be the cause of a VCF, a biopsy is needed to confirm a cancer diagnosis. RT is reserved for metastatic spinal disease and typically for those spinal metastases causing pain, neurologic compromise, or those asymptomatic lesions with radiologic features suggesting a risk of neurologic compromise or VCF.

Variant 6: Symptomatic osteoporotic VCF with bone marrow edema or intravertebral cleft. Initial treatment.
F. Systemic Radionuclide Therapy

This procedure is not useful for benign osteoporosis-related compressions fractures.

Variant 7: New symptomatic VCF. History of prior vertebroplasty or surgery. Initial treatment.

Patients can develop additional VCFs in an adjacent vertebra or at another vertebral level after successful VA with potential risk factors including patient's bone mineral density, early postprocedure activity, and chronic corticosteroid use, which can lead to an increased risk of refracture or development of adjacent level fractures in the first few months after the procedure. However, there is a very small subgroup of patients who have no pain relief or even worsening

pain after the VA, perhaps indicating continued progression of the treated fracture or development of a new fracture at the previously treated site. The causes of failure of the initial VA procedure include inadequate filling of the fracture site and persistent or increasing intravertebral fluid-filled clefts. The presence of an unfilled intravertebral fluid cleft on preoperative diagnostic studies is an important indicator of risk for progression, as is the later development of fluid at the bone cement interface. A recurrent fracture at a level previously treated with kyphoplasty or VP is very rare, varying from <1% to 2% of cases in a large series [131]. One of the largest studies reported with a 2 year follow-up study of 1,800 patients, only 10, or 0.56%, developed a recurrent same level fracture after VP [132].

Variant 7: New symptomatic VCF. History of prior vertebroplasty or surgery. Initial treatment.
A. Medical Management Only

Medical management is complementary to other therapies and should be offered in all clinical scenarios. Conservative management includes medical management with or without methods of immobility [36,107,108]. If there is failure of medical management with worsening of symptoms to medications or in the setting of spinal deformity or pulmonary dysfunction, other management alternatives should be considered.

Patients complaining of significant pain after undergoing a VA must be re-evaluated with radiographs, CT, and MRI scans because the increased pain maybe due to progression of fracture at the same level or development of adjacent level fracture.

Variant 7: New symptomatic VCF. History of prior vertebroplasty or surgery. Initial treatment.
B. Percutaneous Vertebral Augmentation

A recent meta-analysis from 2017 comprising 1,328 patients found no increased risk for adjacent or remote level vertebral body fracture following augmentation using VP or BK compared with nonsurgical management. Of the randomized control trials discussed in this document, only 2 studies showed a statistically significant difference in the rate of adjacent vertebral fractures in follow-up between the VA and control groups, one favoring VA and the other nonsurgical management. In addition, VP and BK may be protective against further height loss of a fractured vertebra. In the VERTOS IV trial, the risk of further height loss was almost 10 times higher after the sham procedure compared with VA treatment [133,134].

Patients with ongoing compression at a previously treated level can undergo a second augmentation, especially if the initial fluid-filled cleft did not completely fill or the cleft enlarges afterward. In several large studies, intravertebral clefts were identified in between 90% and 100% of cases of recurrent fractures in a previously treated level [135,136]. The goal is more uniform filling of the vertebra to decrease the micromotion at the fractured vertebral endplates, which helps in pain palliation. After initial augmentation, the development of a new adjacent level fracture can also be addressed by repeating the procedure for the new fracture level.

Variant 7: New symptomatic VCF. History of prior vertebroplasty or surgery. Initial treatment.
C. Percutaneous Ablation Spine

Percutaneous thermal ablation procedures are reserved for symptomatic spinal metastatic disease [112].

Variant 7: New symptomatic VCF. History of prior vertebroplasty or surgery. Initial treatment.
D. Surgical Consultation

Surgery is typically reserved for patients who have developed new neurologic compromise, new spinal instability, or leakage of cement into the spinal epidural space with canal compression and the development of new radicular symptoms. Observational studies suggest that surgical decompression and stabilization improve neurological status from nonambulatory to ambulatory as well as pain relief [137]. Surgical consultation can be performed concurrently with other procedures.

Variant 7: New symptomatic VCF. History of prior vertebroplasty or surgery. Initial treatment.
E. Radiation Oncology Consultation

There is no role for RT in a patient without a cancer diagnosis and a nonpathologic VCF. If cancer is thought to be the cause of a VCF, a biopsy is needed to confirm a cancer diagnosis. RT is reserved for metastatic spinal disease and typically for those spinal metastases causing pain, neurologic compromise, or those asymptomatic lesions with radiologic features suggesting a risk of neurologic compromise or VCF.

Variant 7: New symptomatic VCF. History of prior vertebroplasty or surgery. Initial treatment.
F. Systemic Radionuclide Therapy

This procedure is not useful for this clinical scenario.

Variant 8: Benign VCF with worsening pain, deformity, or pulmonary dysfunction. Initial treatment.

Most VCFs show a gradual improvement in pain over 2 to 12 weeks, with a variable return of function [103,104]. Bone marrow edema associated with acute fractures on MRI typically resolves within 1 to 3 months [50,51].

Because conservative medical treatment does not prevent further collapse and does not prevent kyphosis, the timing of intervention has been an issue of debate. The VERTOS II trial, a randomized control trial comparing VA with medical management, revealed that 40% of conservatively treated patients had no significant pain relief after 1 year despite higher class prescription medication [34]. Approximately 1 in 5 patients with osteoporotic VCFs will develop chronic back pain as a result of the fracture [105,106]. Additionally, spinal deformity associated with VCF can contribute to impaired mobility and physical functioning. Spinal deformity may be defined as ≥15% kyphosis, ≥10% scoliosis, ≥10% dorsal wall height reduction, or vertebral body height loss ≥20% [107].

Variant 8: Benign VCF with worsening pain, deformity, or pulmonary dysfunction. Initial treatment.
A. Medical Management Only

Medical management is complementary to other therapies and should be offered in all clinical scenarios. Conservative management includes medical management with or without methods of immobility and is the initial treatment of painful VCFs [36,107,108].

Patients may not be candidates for percutaneous or surgical intervention because of factors related to performance status, pregnancy, infection, or coagulation disorders, among others.

Clinical decision-making must account for the overall risk and benefit to the patient.

Variant 8: Benign VCF with worsening pain, deformity, or pulmonary dysfunction. Initial treatment.

B. Percutaneous Vertebral Augmentation

VA may be a treatment option [36,107] for osteoporotic VCFs because there is evidence that VA is associated with better pain relief and improved functional outcomes compared to conservative therapy [21,23,32,34]. VA has shown immediate and considerable improvement in pain and patient mobility. This supports consideration of VA to abate the secondary sequelae of VCFs, such as decreased bone mineral density and muscle strength with immobility [138,139], increased risk of deep venous thrombosis [138], and deconditioning of cardiovascular and respiratory muscles [1,139]. Because of improved alignment and decreased pain, VA has been shown to improve pulmonary function in patients with VCF [89,123,124,140]. Certain newer variants of VA are shown to be comparable to standard methods, such as BK, for decreased pain score, functional improvement, and height restoration [17,141].

The timing of when VA is useful has been debated. In the VERTOS II trial, of the patients who had significant pain relief on medical management, the majority achieved this level by 3 months; this study suggested that patients who had not received sufficient pain relief by 3 months with conservative treatment may be candidates for VA [34]. Studies have found VA to be superior to placebo intervention for pain reduction in patients with acute osteoporotic VCF of <6 weeks duration [22]. As noted in Variant 1 in the study by Syed et al [33], patients with VCF >12 weeks compared with VCF <12 weeks had equivalent benefit suggesting that the age of the fracture does not independently affect the outcomes of VA, although there is evidence for treatment of subacute and chronic, painful compression fractures [21,23,31,32].

Many studies have compared VP versus BK. A randomized control trial by Evans et al [27] found that VP and BK are equally effective in substantially reducing pain and disability in such patients. Others have corroborated these findings with improvements in vertebral deformity and less cement leakage with BK [25,26]. This comparable effectiveness between VA techniques in clinical outcomes has been shown to persist from 2 years [26] to 5 years [28] after the procedure. The improvement in spinal deformity with an extension of the kyphotic angle and increased vertebral body height with BK has been shown to provide superior functional recovery compared with VP [30]. Unilateral versus bilateral VP techniques have shown no statistical difference in visual analog scale score, Oswestry disability index, Short Form-36, cement leakage rate, or vertebral height restoration [24,29]. Because clinical outcome studies show essentially the same benefit of BK as VP for patient pain relief and mobility and similar complication rates, a multisociety (ACR–ASNR–ASSR–SIR–SNIS) panel of spine interventionalists holds the position that BK or VP may be considered to be useful and generally interchangeable techniques for the performance of VA [36].

Variant 8: Benign VCF with worsening pain, deformity, or pulmonary dysfunction. Initial treatment.

C. Percutaneous Ablation Spine

Percutaneous thermal ablation procedures are reserved for symptomatic spinal metastatic disease [112].

Variant 8: Benign VCF with worsening pain, deformity, or pulmonary dysfunction. Initial treatment.

D. Surgical Consultation

Surgical intervention is reserved for patients with neurologic deficits or spinal instability. When the etiology of the VCF is questionable and percutaneous biopsy is not feasible, an open biopsy may be necessary. Surgical consultation can assist in prescribing and supervising immobilization devices.

Variant 8: Benign VCF with worsening pain, deformity, or pulmonary dysfunction. Initial treatment.

E. Radiation Oncology Consultation

There is no role for RT in a patient without a cancer diagnosis and a nonpathologic VCF. If cancer is thought to be the cause of a VCF, then a biopsy is needed to confirm a cancer diagnosis. RT is reserved for metastatic spinal disease and typically for those spinal metastases causing pain, neurologic compromise, or those asymptomatic lesions with radiologic features suggesting a risk of neurologic compromise or VCF.

Variant 8: Benign VCF with worsening pain, deformity, or pulmonary dysfunction. Initial treatment.

F. Systemic Radionuclide Therapy

This procedure is not useful for this clinical scenario but this therapy maybe an option for pain palliation in patients with multifocal osteoblastic metastases, particularly hormone-resistant prostate and breast cancers. The radionuclides are incorporated into the bony matrix and emit radioactive alpha or beta particles that reduce tumor volume and decrease the production of pain sensitive cytokines

Variant 9: Pathological VCF with ongoing or increasing mechanical pain. Initial treatment.

Variant 9: Pathological VCF with ongoing or increasing mechanical pain. Initial treatment.

A. Medical Management Only

Medical management is complementary to other therapies and should be offered in all clinical scenarios. Upon presentation with neurological deficits, the patient should be treated with corticosteroid therapy, and treatment should be initiated as soon as possible to prevent further neurological deterioration [142].

Variant 9: Pathological VCF with ongoing or increasing mechanical pain. Initial treatment.

B. Percutaneous Ablation Spine

Image-guided ablative therapies demonstrate potential advantages, including reduced morbidity, lower procedural suitability for real-time imaging guidance, the ability to perform therapy in an outpatient setting, synergy with other cancer treatments, repeatability, and short procedural time [143]. Percutaneous thermal ablation of vertebral metastases is a valid therapeutic option for the following patient subgroups: patients with a life expectancy of more than 6 months, good performance status, and few visceral metastases; uncomplicated (lack of metastatic epidural spinal cord compression), painful spinal metastases; and stable pathologic VCF. Percutaneous thermal ablation has been demonstrated to be an effective treatment option for the management of vertebral metastases with an excellent safety profile. The local tumor control rates of percutaneous thermal ablation of spinal osseous metastatic disease have been reported at 70% to 96% in several case series [144-146]. Implementation of appropriate patient selection guidelines, the optimal choice of ablation modality, and the use of thermal protection when necessary are major contributors to improved treatment outcomes.

RFA is typically used to treat osteolytic or mixed osteolytic-osteoblastic vertebral (body and/or posterior elements) tumors without soft tissue components. RFA is often ineffective in treating primarily osteoblastic lesions because of the high impedance of densely sclerotic bone [145].

Microwave ablation uses electromagnetic waves to agitate water molecules, producing friction and heat that induces cellular death via coagulation necrosis. Microwave ablation is more effective in high-impedance tissues like bone because poor thermal conduction in bone may be at times a limiting factor in RFA. Osseous relative permeability and low conduction help microwaves penetrate deeper and are more effective in thermal ablation than RFA. Microwave ablation is a promising, safe, and effective treatment for osseous tumors, resulting in both a reduction in pain and a degree of locoregional control of the disease process [143].

Cryoablation results in the formation of a hypoattenuating ice ball, which is readily identified by CT, beyond which tissues are safe from thermal injury. Additional advantages of cryoablation are decreased intraprocedural and postprocedural pain, the ability to use multiple probes in various orientations to achieve additive overlapping ablation zones, and efficiency in treating osteoblastic metastases [147]. Typically followed VA procedure patients should still be considered for radiation.

Variant 9: Pathological VCF with ongoing or increasing mechanical pain. Initial treatment. C. Percutaneous Vertebral Augmentation

VA is a safe and effective treatment for vertebrae weakened by neoplasia [148]. VA provides analgesia and structural reinforcement more rapidly than other treatment measures [149]. Certain newer variants of VA have been shown to be comparable to standard methods, such as BK, in decreasing pain scores and functional improvement [17]. VCFs following SBRT are also amenable to VA. Typically followed VA procedure patients should still be considered for radiation.

Variant 9: Pathological VCF with ongoing or increasing mechanical pain. Initial treatment. D. Surgical Consultation

Surgery is the standard of care for pathologic VCF complicated by frank spinal instability and/or neurologic deficits. The SINS can be used to categorize the metastatic spinal segment as stable, potentially unstable, or unstable based on anatomic and clinical factors [150] and can guide surgical referral [14,150]. In the setting of metastatic spinal cord compression, mainly because of osseous compression, surgery is more likely to allow recovery compared to RT alone [151]. Observational studies suggest that surgical decompression, tumor excision, and stabilization improve neurological status from nonambulatory to ambulatory and provide pain relief [137]. Decompressive surgery followed by RT may benefit symptomatic spinal cord compression in patients who are <65 years of age, in the setting of a single level of compression, in patients with neurologic deficits for <48 hours, and in those patients with a predicted survival of at least 3 months [152]. The combination of a spine stabilization procedure and RT may also help manage axial pain and aid in neurologic recovery [153].

A large prospective randomized trial shows that patients with metastatic epidural spinal cord compression treated with direct decompressive surgery plus postoperative radiotherapy retain the ability to walk for longer and regain the ability more often than patients treated with radiotherapy alone. Surgery allows most patients to remain ambulatory for the remainder of their lives, whereas patients treated with radiation alone spend a substantial proportion of their remaining time paraplegic. Surgical treatment also results in increased survival time. The better survival time in the surgical group was probably because a greater proportion of patients in this group were

ambulatory and remained so for longer than those in the radiation group. Therefore, patients in the surgery group were less susceptible to infections, blood clots, and other problems that result in the death of paraplegic patients. Surgical treatment also reduces the need for corticosteroids and opioid pain relief [154]. Palliative surgery using posterior decompression and fixation combined with intraoperative VA to treat spinal metastases with osseous and epidural disease can improve neurological function, alleviate pain effectively, and allow low cement leakage and timely disposal of leakage if it happens [155].

Variant 9: Pathological VCF with ongoing or increasing mechanical pain. Initial treatment. E. Radiation Oncology Consultation

The current standard of care for the management of diffuse painful osseous metastases is external beam RT [156] for at least partial pain palliation [157]. A short course, such as 8 Gy in 1 fraction (as opposed to 20 Gy in 5 fractions or 30 Gy in 10 fractions), is best for patients who have radiosensitive tumors (hematologic primary, seminoma, small-cell lung cancer) or have a poor survival prognosis (<3 months). Some studies have demonstrated benefit in up to 70% of patients treated with respect to neurologic improvement for patients with symptomatic spinal cord compression [158,159]. Advancements in radiotherapy have allowed for the delivery of high precision dose-escalated treatment, known as SBRT, to targets throughout the body with excellent local control rates. Recently, the first phase II randomized trial comparing conventional radiotherapy to comprehensive SBRT of oligometastatic disease demonstrated an overall survival and progression-free survival advantage [160]. The spine is a common site of metastasis and a complex site for SBRT given the adjacent spinal cord and the tumor embedded within the bone tissue putting the patient at risk of fracture [161]. SBRT delivers precise, high-dose radiation to the target region while sparing the spinal cord and provides satisfactory efficacy and an acceptable safety profile for spinal metastases. A recent landmark randomized phase 3 trial led by Sahgal et al [162] showed that SBRT delivering 24 Gy in 2 fractions was superior to conventional radiotherapy delivering 20 Gy in 5 fractions for patients with limited painful spinal metastases. They reported an 11% risk of VCF in the SBRT arm and superior complete response rates for pain at 3 and 6 months posttreatment with SBRT [162].

No comparative randomized trials have been performed to establish optimal dosing of spine SBRT. Single-fraction SBRT may result in a higher local control rate than those of the other fractionations, particularly with 24 Gy in 1 fraction. However, high-dose single fraction SBRT comes at the expense of a greater rate of vertebral fracture, which can even approximate 40% [96]. At present, the dose of spine SBRT varies from 18 to 24 Gy in 1 fraction, 24 Gy in 2 fractions, and 24 to 40 Gy in 3 to 5 fractions [95]. A study by Chen et al [163] using normal tissue complication probability modeling suggests that the larger volume of the vertebral segment receiving lower doses is more closely associated with post-SBRT VCF than high dose regions, and technical developments in spine SBRT continue to evolve with respect to mitigating the risk of iatrogenic fracture. Typically VCF secondary to radiation can be managed with a cement augmentation procedure, and there is increasing use of cement augmentation procedures prophylactically to mitigate the risk of iatrogenic VCF [15,164]. Postoperative SBRT has also been increasingly used with promising results [165] and should be considered in selected patients to optimize local tumor control.

Variant 9: Pathological VCF with ongoing or increasing mechanical pain. Initial treatment. F. Systemic Radionuclide Therapy

Systemic radionuclide therapy may be an option for palliation of multifocal osteoblastic metastases, particularly hormone-resistant prostate and breast cancer. The radionuclides are

incorporated into the bone matrix at sites of increased osteoblastic activity and emit radioactive alpha or beta particles that reduce tumor volume and decrease the production of pain-sensitizing cytokines [166]. Radioisotopes are effective in providing pain relief 1 to 4 weeks after initiation, with response rates of between 40% and 95% that can continue for up to 18 months. For example, a prospective study on the palliative efficacy of strontium-89 showed an overall response rate of 76% and a complete response rate of 32% [167]. Repeat doses are effective in providing pain relief in many patients. The combination with chemotherapeutic agents, such as cisplatin, can increase the effectiveness of radioisotopes. Radionuclides may also be used to prevent skeletal-related events, as in the use of radium-223 for patients with multiple spinal metastases from castration-resistant prostate cancer.

Summary of Recommendations

- **Variant 1**: When a new, symptomatic VCF is identified on radiographs with no history of malignancy, either CT or MRI of the spine without IV contrast is recommended as the next imaging study to differentiate between acute/subacute and chronic fractures and to evaluate for complications. Either procedure can be performed, but they may be complementary when knowledge of bony anatomy is relevant to treatment planning. Bone scan, SPECT, or SPECT/CT of the whole spine may be appropriate as complementary alternatives in cases in which there are multiple fractures or concern for more widespread distribution of fractures.
- **Variant 2**: When a new, symptomatic VCF is identified on radiographs with a history of malignancy, both CT of the spine without IV contrast, or MRI of the spine either without or with and without IV contrast is recommended as the next imaging study to differentiate between acute/subacute and chronic fractures, enhancing tumor, and to evaluate for complications. Either procedure can be performed, but they may also be complementary when knowledge of bony anatomy is relevant to treatment planning. Other procedures including bone scan, SPECT or SPECT/CT of the whole spine, and FDG-PET/CT may be appropriate in cases in which there are multiple fractures or concern for more widespread distribution of fractures.
- **Variant 3**: In the setting of new back pain and either previously treated VCF or multiple VCFs, either CT or MRI of the spine without IV contrast is recommended as the initial imaging study. MRI of the spine with and without IV contrast may be useful to assess for inflammation but should be carefully assessed because it is prone to artifactual distortion. Other procedures including bone scan, SPECT or SPECT/CT of the whole spine, and FDG-PET/CT may be appropriate in cases in which there are multiple fractures or concern for more widespread distribution of fractures.
- **Variant 4**: When an asymptomatic VCF is identified on radiographs and there is a history of malignancy, both CT of the spine without IV contrast, or MRI of the spine either without or with and without IV contrast is recommended as the next imaging study to evaluate for bone marrow edema, enhancing tumor, or other complication. Either procedure can be performed, but they may also be complementary in certain circumstances. Other procedures including bone scan, SPECT or SPECT/CT of the whole spine, and FDG-PET/CT may be appropriate in cases in which there are multiple fractures or concern for more widespread distribution of fractures. Image-guided biopsy may be useful when tissue sampling is needed before treatment.
- **Variant 5**: In the setting of an asymptomatic, osteoporotic VCF, medical management only is usually appropriate as the initial treatment. Other treatments are usually not appropriate at

this stage.

- **Variant 6**: In the setting of a symptomatic osteoporotic VCF with bone marrow edema or intravertebral cleft, both medical management and percutaneous VA are usually appropriate as initial treatment strategies. Medical management is always appropriate and is complementary to VA and should never be omitted even when intervention is performed. Surgical consultation may be appropriate depending on fracture morphology and patient-related factors.
- **Variant 7 and Variant 8**: In the setting of either a new, symptomatic VCF and history of prior VP or surgery, or in the setting of benign VCF with worsening pain, deformity, or pulmonary dysfunction, both medical management and percutaneous VA are usually appropriate as initial treatment strategies. Medical management is always appropriate and is complementary to VA and should never be omitted even when intervention is performed. Surgical consultation may be appropriate depending on fracture morphology and patient-related factors.
- **Variant 9**: In the setting of a pathological VCF with ongoing or increasing mechanical pain, surgical consultation and/or radiation oncology consultation are usually appropriate. Treatment with percutaneous VA and/or in combination with percutaneous spinal ablation treatment are also usually appropriate and may be complementary. Medical management only or systemic radionuclide therapy may be appropriate in this context as well.

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at https://acsearch.acr.org/list. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents, please go to the ACR website at https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.

Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

References

1. Teasell R, Dittmer DK. Complications of immobilization and bed rest. Part 2: Other complications. [Review] [23 refs]. Can Fam Physician. 39:1440-2, 1445-6, 1993 Jun.
2. Radvany MG, Murphy KJ, Millward SF, et al. Research reporting standards for percutaneous vertebral augmentation. J Vasc Interv Radiol. 2009; 20(10):1279-1286.
3. Expert Panel on Musculoskeletal Imaging:, Ward RJ, Roberts CC, et al. ACR Appropriateness Criteria R Osteoporosis and Bone Mineral Density. [Review]. J. Am. Coll. Radiol.. 14(5S):S189-S202, 2017 May.
4. Kim DH, Vaccaro AR. Osteoporotic compression fractures of the spine; current options and considerations for treatment. Spine J. 2006; 6(5):479-487.
5. Lane NE. Epidemiology, etiology, and diagnosis of osteoporosis. Am J Obstet Gynecol. 2006; 194(2 Suppl):S3-11.
6. Siris ES, Brenneman SK, Barrett-Connor E, et al. The effect of age and bone mineral density on the absolute, excess, and relative risk of fracture in postmenopausal women aged 50-99: results from the National Osteoporosis Risk Assessment (NORA). Osteoporos Int. 2006; 17(4):565-574.
7. Kanis JA, Johnell O, Oden A, De Laet C, Mellstrom D. Epidemiology of osteoporosis and fracture in men. [Review] [80 refs]. Calcif Tissue Int. 75(2):90-9, 2004 Aug.
8. Center JR, Nguyen TV, Schneider D, Sambrook PN, Eisman JA. Mortality after all major types of osteoporotic fracture in men and women: an observational study. Lancet. 353(9156):878-82, 1999 Mar 13.
9. Hinde K, Maingard J, Hirsch JA, Phan K, Asadi H, Chandra RV. Mortality Outcomes of Vertebral Augmentation (Vertebroplasty and/or Balloon Kyphoplasty) for Osteoporotic Vertebral Compression Fractures: A Systematic Review and Meta-Analysis. Radiology. 295(1):96-103, 2020 04.
10. Hirsch JA, Chandra RV, Carter NS, Beall D, Frohbergh M, Ong K. Number Needed to Treat with Vertebral Augmentation to Save a Life. AJNR Am J Neuroradiol. 41(1):178-182, 2020 01.
11. Schajowicz F. Aneurysmal bone cyst. In: Schajowicz F, ed. Histologic Typing of Bone Tumors. 2nd ed. Berlin, Germany: Springer-Verlag; 1992:37.
12. Kallmes DF, Jensen ME. Percutaneous vertebroplasty. Radiology. 2003; 229(1):27-36.
13. McGirt MJ, Parker SL, Wolinsky JP, Witham TF, Bydon A, Gokaslan ZL. Vertebroplasty and kyphoplasty for the treatment of vertebral compression fractures: an evidenced-based review of the literature. Spine J. 2009; 9(6):501-508.
14. Fourney DR, Frangou EM, Ryken TC, et al. Spinal instability neoplastic score: an analysis of reliability and validity from the spine oncology study group. J Clin Oncol. 29(22):3072-7, 2011 Aug 01.

15. Faruqi S, Tseng CL, Whyne C, et al. Vertebral Compression Fracture After Spine Stereotactic Body Radiation Therapy: A Review of the Pathophysiology and Risk Factors. Neurosurgery 2017:[E-pub ahead of print].

16. Bilsky MH, Laufer I, Fourney DR, et al. Reliability analysis of the epidural spinal cord compression scale. J Neurosurg Spine. 13(3):324-8, 2010 Sep.

17. Korovessis P, Vardakastanis K, Vitsas V, Syrimpeis V. Is Kiva implant advantageous to balloon kyphoplasty in treating osteolytic metastasis to the spine? Comparison of 2 percutaneous minimal invasive spine techniques: a prospective randomized controlled short-term study. Spine. 39(4):E231-9, 2014 Feb 15.

18. Ortiz AO.. Use and evaluation of a semi-permeable mesh implant in vertebral augmentation for the treatment of painful osteoporotic vertebral compression fractures. Journal of Neurointerventional Surgery. 8(3):328-32, 2016 Mar.

19. Renaud C.. Treatment of vertebral compression fractures with the cranio-caudal expandable implant SpineJack: Technical note and outcomes in 77 consecutive patients. Orthopaedics & traumatology, surgery & research. 101(7):857-9, 2015 Nov.

20. Tutton SM, Pflugmacher R, Davidian M, Beall DP, Facchini FR, Garfin SR. KAST Study: The Kiva System As a Vertebral Augmentation Treatment-A Safety and Effectiveness Trial: A Randomized, Noninferiority Trial Comparing the Kiva System With Balloon Kyphoplasty in Treatment of Osteoporotic Vertebral Compression Fractures. Spine (Phila Pa 1976). 2015;40(12):865-875.

21. Chen D, An ZQ, Song S, Tang JF, Qin H. Percutaneous vertebroplasty compared with conservative treatment in patients with chronic painful osteoporotic spinal fractures. Journal of Clinical Neuroscience. 21(3):473-7, 2014 Mar.

22. Clark W, Bird P, Gonski P, et al. Safety and efficacy of vertebroplasty for acute painful osteoporotic fractures (VAPOUR): a multicentre, randomised, double-blind, placebo-controlled trial. Lancet. 388(10052):1408-1416, 2016 Oct 01.

23. Farrokhi MR, Alibai E, Maghami Z. Randomized controlled trial of percutaneous vertebroplasty versus optimal medical management for the relief of pain and disability in acute osteoporotic vertebral compression fractures. Journal of Neurosurgery Spine. 14(5):561-9, 2011 May.

24. Chen C, Bian J, Zhang W, Zhang W, Zhao C, Wei H. Unilateral versus bilateral vertebroplasty for severe osteoporotic vertebral compression fractures. Journal of Spinal Disorders & Techniques. 27(8):E301-4, 2014 Dec.

25. Dohm M, Black CM, Dacre A, Tillman JB, Fueredi G, KAVIAR investigators. A randomized trial comparing balloon kyphoplasty and vertebroplasty for vertebral compression fractures due to osteoporosis. Ajnr: American Journal of Neuroradiology. 35(12):2227-36, 2014 Dec.

26. Du J, Li X, Lin X. Kyphoplasty versus vertebroplasty in the treatment of painful osteoporotic vertebral compression fractures: two-year follow-up in a prospective controlled study. Acta Orthopaedica Belgica. 80(4):477-86, 2014 Dec.

27. Evans AJ, Kip KE, Brinjikji W, et al. Randomized controlled trial of vertebroplasty versus kyphoplasty in the treatment of vertebral compression fractures. Journal of Neurointerventional Surgery. 8(7):756-63, 2016 Jul.

28. Liu JT, Li CS, Chang CS, Liao WJ. Long-term follow-up study of osteoporotic vertebral compression fracture treated using balloon kyphoplasty and vertebroplasty. Journal of Neurosurgery Spine. 23(1):94-8, 2015 Jul.

29. Zhang L, Liu Z, Wang J, et al. Unipedicular versus bipedicular percutaneous vertebroplasty for osteoporotic vertebral compression fractures: a prospective randomized study. BMC Musculoskeletal Disorders. 16:145, 2015 Jun 14.

30. Zhao DH, Chen K, Zhu J, Yang X, Dong F, Wang WB. Postoperative Functional Evaluation of Percutaneous Vertebroplasty Compared With Percutaneous Kyphoplasty for Vertebral Compression Fractures. American Journal of Therapeutics. 23(6):e1381-e1390, 2016 Nov/Dec.

31. Brown DB, Gilula LA, Sehgal M, Shimony JS. Treatment of chronic symptomatic vertebral compression fractures with percutaneous vertebroplasty. AJR Am J Roentgenol. 182(2):319-22, 2004 Feb.

32. Nieuwenhuijse MJ, van Erkel AR, Dijkstra PD. Percutaneous vertebroplasty for subacute and chronic painful osteoporotic vertebral compression fractures can safely be undertaken in the first year after the onset of symptoms. Journal of Bone & Joint Surgery - British Volume. 94(6):815-20, 2012 Jun.

33. Syed MI, Shaikh A, Cortoss Study Group. Does age of fracture affect the outcome of vertebroplasty? Results from data from a prospective multicenter FDA IDE study. Journal of Vascular & Interventional Radiology. 23(11):1416-22, 2012 Nov.

34. Venmans A, Klazen CA, Lohle PN, Mali WP, van Rooij WJ. Natural history of pain in patients with conservatively treated osteoporotic vertebral compression fractures: results from VERTOS II. AJNR Am J Neuroradiol. 33(3):519-21, 2012 Mar.

35. American College of Radiology. ACR–ASNR–ASSR–SIR–SNIS Practice Parameter for the Performance of Vertebral Augmentation. Available at: https://gravitas.acr.org/PPTS/GetDocumentView?docId=161+&releaseId=2

36. Barr JD, Jensen ME, Hirsch JA, et al. Position Statement on Percutaneous Vertebral Augmentation: A Consensus Statement Developed by the Society of Interventional Radiology (SIR), American Association of Neurological Surgeons (AANS) and the Congress of Neurological Surgeons (CNS), American College of Radiology (ACR), American Society of Neuroradiology (ASNR), American Society of Spine Radiology (ASSR), Canadian Interventional Radiology Association (CIRA), and the Society of NeuroInterventional Surgery (SNIS). J Vasc Interv Radiol. 2014;25(2):171-181.

37. Yang PL, He XJ, Li HP, Zang QJ, Wang GY. Image-guided minimally invasive percutaneous treatment of spinal metastasis. Experimental Ther. Med.. 13(2):705-709, 2017 Feb.

38. Parizel PM, van der Zijden T, Gaudino S, et al. Trauma of the spine and spinal cord: imaging strategies. Eur Spine J. 2010; 19 Suppl 1:S8-17.

39. Nairn RJ, Binkhamis S, Sheikh A. Current perspectives on percutaneous vertebroplasty: current evidence/controversies, patient selection and assessment, and technique and complications. Radiol Res Pract. 2011; 2011:175079.

40. Diekhoff T, Hermann KG, Pumberger M, Hamm B, Putzier M, Fuchs M. Dual-energy CT virtual non-calcium technique for detection of bone marrow edema in patients with vertebral fractures: A prospective feasibility study on a single- source volume CT scanner.

European Journal of Radiology. 87:59-65, 2017 Feb.

41. Karaca L, Yuceler Z, Kantarci M, et al. The feasibility of dual-energy CT in differentiation of vertebral compression fractures. Br J Radiol. 89(1057):20150300, 2016.

42. Kaup M, Wichmann JL, Scholtz JE, et al. Dual-Energy CT-based Display of Bone Marrow Edema in Osteoporotic Vertebral Compression Fractures: Impact on Diagnostic Accuracy of Radiologists with Varying Levels of Experience in Correlation to MR Imaging. Radiology. 280(2):510-9, 2016 Aug.

43. Benz BK, Gemery JM, McIntyre JJ, Eskey CJ. Value of immediate preprocedure magnetic resonance imaging in patients scheduled to undergo vertebroplasty or kyphoplasty. Spine (Phila Pa 1976). 2009; 34(6):609-612.

44. Ma X, Wang LX, Wang HL, Jiang L, Lu FZ, Jiang JY. Value of preoperative magnetic resonance imaging measurements in thoracic percutaneous vertebroplasty using unilateral. Chin Med J (Engl). 2010; 123(21):2983-2988.

45. Spiegl UJ, Beisse R, Hauck S, Grillhosl A, Buhren V. Value of MRI imaging prior to a kyphoplasty for osteoporotic insufficiency fractures. Eur Spine J. 2009; 18(9):1287-1292.

46. Park SY, Lee SH, Suh SW, Park JH, Kim TG. Usefulness of MRI in determining the appropriate level of cement augmentation for acute osteoporotic vertebral compression fractures. Journal of Spinal Disorders & Techniques. 26(3):E80-5, 2013 May.

47. Yang HL, Wang GL, Niu GQ, et al. Using MRI to determine painful vertebrae to be treated by kyphoplasty in multiple-level vertebral compression fractures: a prospective study. Journal of International Medical Research. 36(5):1056-63, 2008 Sep-Oct.

48. Pizones J, Izquierdo E, Alvarez P, et al. Impact of magnetic resonance imaging on decision making for thoracolumbar traumatic fracture diagnosis and treatment. Eur Spine J. 20 Suppl 3:390-6, 2011 Aug.

49. Tsujio T, Nakamura H, Terai H, et al. Characteristic radiographic or magnetic resonance images of fresh osteoporotic vertebral fractures predicting potential risk for nonunion: a prospective multicenter study. Spine (Phila Pa 1976). 2011; 36(15):1229-1235.

50. Piazzolla A, Solarino G, Lamartina C, et al. Vertebral Bone Marrow Edema (VBME) in Conservatively Treated Acute Vertebral Compression Fractures (VCFs): Evolution and Clinical Correlations. Spine. 40(14):E842-8, 2015 Jul 15.

51. Voormolen MH, van Rooij WJ, van der Graaf Y, et al. Bone marrow edema in osteoporotic vertebral compression fractures after percutaneous vertebroplasty and relation with clinical outcome. AJNR Am J Neuroradiol. 27(5):983-8, 2006 May.

52. Tang ZB, Lei Z, Yang HL, Chen KW. Value of bone scan imaging in determining painful vertebrae of osteoporotic vertebral compression fractures patients with contraindications to MRI. Orthop Surg. 4(3):172-6, 2012 Aug.

53. Jordan E, Choe D, Miller T, Chamarthy M, Brook A, Freeman LM. Utility of bone scintigraphy to determine the appropriate vertebral augmentation levels. Clinical Nuclear Medicine. 35(9):687-91, 2010 Sep.

54. Karam M, Lavelle WF, Cheney R. The role of bone scintigraphy in treatment planning, and predicting pain relief after kyphoplasty. Nuclear Medicine Communications. 29(3):247-53, 2008 Mar.

55. Lin HH, Chou PH, Wang ST, Yu JK, Chang MC, Liu CL. Determination of the painful level in osteoporotic vertebral fractures--Retrospective comparison between plain film, bone scan, and magnetic resonance imaging. J Chin Med Assoc. 78(12):714-8, 2015 Dec.

56. Kim JH, Kim JI, Jang BH, Seo JG. The comparison of bone scan and MRI in osteoporotic compression fractures. Asian Spine J. 2010; 4(2):89-95.

57. Kumar K, Halkar RK, Bartley SC, Schuster DM. Incremental benefit of SPECT + CT bone scans over conventional planar and SPECT bone scans in vertebroplasty. Indian J. Nucl. Med.. 26(4):181-4, 2011 Oct.

58. ap Dafydd D, Salem S, Zerizer I, et al. The value of combined assessment of vertebral fractures with 99mTc MDP scintigraphy and MRI in selecting and planning percutaneous vertebroplasty. Nucl Med Commun. 35(7):755-61, 2014 Jul.

59. Sola M, Perez R, Cuadras P, et al. Value of bone SPECT-CT to predict chronic pain relief after percutaneous vertebroplasty in vertebral fractures. Spine Journal: Official Journal of the North American Spine Society. 11(12):1102-7, 2011 Dec.

60. Li YB, Zheng X, Wang R, et al. SPECT-CT versus MRI in localizing active lesions in patients with osteoporotic vertebral compression fractures. Nucl Med Commun. 39(7):610-617, 2018 Jul.

61. Schmitz A, Risse JH, Textor J, et al. FDG-PET findings of vertebral compression fractures in osteoporosis: preliminary results. Osteoporos Int. 13(9):755-61, 2002 Sep.

62. Gratz S, Dorner J, Fischer U, et al. 18F-FDG hybrid PET in patients with suspected spondylitis. Eur J Nucl Med Mol Imaging. 29(4):516-24, 2002 Apr.

63. De Winter F, Gemmel F, Van De Wiele C, Poffijn B, Uyttendaele D, Dierckx R. 18-Fluorine fluorodeoxyglucose positron emission tomography for the diagnosis of infection in the postoperative spine. Spine. 28(12):1314-9, 2003 Jun 15.

64. McHenry MC, Duchesneau PM, Keys TF, Rehm SJ, Boumphrey FR. Vertebral osteomyelitis presenting as spinal compression fracture. Six patients with underlying osteoporosis. [Review] [25 refs]. Arch Intern Med. 148(2):417-23, 1988 Feb.

65. Mauch JT, Carr CM, Cloft H, Diehn FE. Review of the Imaging Features of Benign Osteoporotic and Malignant Vertebral Compression Fractures. [Review]. AJNR Am J Neuroradiol. 39(9):1584-1592, 2018 09.

66. Takigawa T, Tanaka M, Sugimoto Y, Tetsunaga T, Nishida K, Ozaki T. Discrimination between Malignant and Benign Vertebral Fractures Using Magnetic Resonance Imaging. Asian spine j.. 11(3):478-483, 2017 Jun.

67. Torres C, Hammond I. Computed Tomography and Magnetic Resonance Imaging in the Differentiation of Osteoporotic Fractures From Neoplastic Metastatic Fractures. J Clin Densitom. 19(1):63-9, 2016 Jan-Mar.

68. Yuh WT, Zachar CK, Barloon TJ, Sato Y, Sickels WJ, Hawes DR. Vertebral compression fractures: distinction between benign and malignant causes with MR imaging. Radiology. 172(1):215-8, 1989 Jul.

69. Cho WI, Chang UK. Comparison of MR imaging and FDG-PET/CT in the differential diagnosis of benign and malignant vertebral compression fractures. J Neurosurg Spine. 14(2):177-83, 2011 Feb.

70. Abdel-Wanis ME, Solyman MT, Hasan NM. Sensitivity, specificity and accuracy of magnetic resonance imaging for differentiating vertebral compression fractures caused by malignancy, osteoporosis, and infections. Journal of Orthopaedic Surgery. 19(2):145-50, 2011 Aug.

71. Kim DH, Rosenblum JK, Panghaal VS, Freeman KD, Lui YW. Differentiating neoplastic from nonneoplastic processes in the anterior extradural space. Radiology. 260(3):825-30, 2011 Sep.

72. Choi J, Raghavan M. Diagnostic imaging and image-guided therapy of skeletal metastases. [Review]. Cancer Control. 19(2):102-12, 2012 Apr.

73. Kim SJ, Lee JS. Diagnostic Performance of F-18 Fluorodeoxyglucose Positron Emission Tomography or Positron Emission Tomography/Computed Tomography for Differentiation of Benign and Malignant Vertebral Compression Fractures: A Meta-Analysis. World Neurosurg. 137:e626-e633, 2020 05.

74. Beheshti M, Rezaee A, Geinitz H, Loidl W, Pirich C, Langsteger W. Evaluation of Prostate Cancer Bone Metastases with 18F-NaF and 18F-Fluorocholine PET/CT. [Review]. J Nucl Med. 57(Suppl 3):55S-60S, 2016 Oct.

75. Muijs SP, Akkermans PA, van Erkel AR, Dijkstra SD. The value of routinely performing a bone biopsy during percutaneous vertebroplasty in treatment of osteoporotic vertebral compression fractures. Spine. 34(22):2395-9, 2009 Oct 15.

76. Martin DJ, Rad AE, Kallmes DF. Prevalence of extravertebral cement leakage after vertebroplasty: procedural documentation versus CT detection. Acta Radiol. 53(5):569-72, 2012 Jun 01.

77. Schmidt R, Cakir B, Mattes T, Wegener M, Puhl W, Richter M. Cement leakage during vertebroplasty: an underestimated problem?. Eur Spine J. 14(5):466-73, 2005 Jun.

78. Lee IJ, Choi AL, Yie MY, et al. CT evaluation of local leakage of bone cement after percutaneous kyphoplasty and vertebroplasty. Acta Radiol. 51(6):649-54, 2010 Jul.

79. Kathuria S. Post-vertebral augmentation spine imaging. [Review]. Neuroimaging Clin N Am. 24(2):337-47, 2014 May.

80. Fossaceca R, Di Terlizzi M, Stecco A, et al. MRI post-vertebroplasty. Radiol Med (Torino). 112(2):185-94, 2007 Mar.

81. Wallace AN, Robinson CG, Meyer J, et al. The Metastatic Spine Disease Multidisciplinary Working Group Algorithms. Oncologist. 20(10):1205-15, 2015 Oct.

82. Lopez-Olivo MA, Shah NA, Pratt G, Risser JM, Symanski E, Suarez-Almazor ME. Bisphosphonates in the treatment of patients with lung cancer and metastatic bone disease: a systematic review and meta-analysis. [Review]. Support Care Cancer. 20(11):2985-98, 2012 Nov.

83. Wong MH, Stockler MR, Pavlakis N. Bisphosphonates and other bone agents for breast cancer. [Review][Update of Cochrane Database Syst Rev. 2005;(3):CD003474; PMID: 16034900]. Cochrane Database Syst Rev. (2)CD003474, 2012 Feb 15.

84. Yuen KK, Shelley M, Sze WM, Wilt T, Mason MD. Bisphosphonates for advanced prostate cancer. [Review] [51 refs]. Cochrane Database Syst Rev. (4)CD006250, 2006 Oct 18.

85. Fizazi K, Carducci M, Smith M, et al. Denosumab versus zoledronic acid for treatment of

bone metastases in men with castration-resistant prostate cancer: a randomised, double-blind study. Lancet. 377(9768):813-22, 2011 Mar 05.

86. Henry DH, Costa L, Goldwasser F, et al. Randomized, double-blind study of denosumab versus zoledronic acid in the treatment of bone metastases in patients with advanced cancer (excluding breast and prostate cancer) or multiple myeloma. J Clin Oncol. 29(9):1125-32, 2011 Mar 20.

87. Stopeck AT, Lipton A, Body JJ, et al. Denosumab compared with zoledronic acid for the treatment of bone metastases in patients with advanced breast cancer: a randomized, double-blind study. J Clin Oncol. 28(35):5132-9, 2010 Dec 10.

88. Sung JK, Jee WH, Jung JY, et al. Differentiation of acute osteoporotic and malignant compression fractures of the spine: use of additive qualitative and quantitative axial diffusion-weighted MR imaging to conventional MR imaging at 3.0 T. Radiology. 271(2):488-98, 2014 May.

89. Tanigawa N, Kariya S, Komemushi A, Nakatani M, Yagi R, Sawada S. Added value of percutaneous vertebroplasty: effects on respiratory function. AJR Am J Roentgenol. 2012; 198(1):W51-54.

90. Kroon HM, Bloem JL, Holscher HC, van der Woude HJ, Reijnierse M, Taminiau AH. MR imaging of edema accompanying benign and malignant bone tumors. Skeletal Radiol 1994;23:261-9.

91. Biffar A, Sourbron S, Dietrich O, et al. Combined diffusion-weighted and dynamic contrast-enhanced imaging of patients with acute osteoporotic vertebral fractures.[Erratum appears in Eur J Radiol. 2011 Mar;77(3):528]. Eur J Radiol. 76(3):298-303, 2010 Dec.

92. Karimi S, Cho NS, Peck KK, Holodny AI. The Role of Advanced Imaging in Spinal Metastases. In: Ramakrishna R, Magge R, Baaj A, Kinisely J, eds. Central Nervous System Metastases: Springer; 2020.

93. Chiewvit P, Danchaivijitr N, Sirivitmaitrie K, Chiewvit S, Thephamongkhol K. Does magnetic resonance imaging give value-added than bone scintigraphy in the detection of vertebral metastasis?. J Med Assoc Thai. 92(6):818-29, 2009 Jun.

94. Wallace AN, Greenwood TJ, Jennings JW. Use of Imaging in the Management of Metastatic Spine Disease With Percutaneous Ablation and Vertebral Augmentation. [Review]. AJR Am J Roentgenol. 205(2):434-41, 2015 Aug.

95. Jabbari S, Gerszten PC, Ruschin M, Larson DA, Lo SS, Sahgal A. Stereotactic Body Radiotherapy for Spinal Metastases: Practice Guidelines, Outcomes, and Risks. [Review]. Cancer J. 22(4):280-9, 2016 Jul-Aug.

96. Sahgal A, Atenafu EG, Chao S, et al. Vertebral compression fracture after spine stereotactic body radiotherapy: a multi-institutional analysis with a focus on radiation dose and the spinal instability neoplastic score. Journal of Clinical Oncology. 31(27):3426-31, 2013 Sep 20.

97. Maynard AS, Jensen ME, Schweickert PA, Marx WF, Short JG, Kallmes DF. Value of bone scan imaging in predicting pain relief from percutaneous vertebroplasty in osteoporotic vertebral fractures. AJNR Am J Neuroradiol. 21(10):1807-12, 2000 Nov-Dec.

98. Cook GJ, Hannaford E, See M, Clarke SE, Fogelman I. The value of bone scintigraphy in the

evaluation of osteoporotic patients with back pain. Scandinavian Journal of Rheumatology. 31(4):245-8, 2002.

99. Gosfield E 3rd, Alavi A, Kneeland B. Comparison of radionuclide bone scans and magnetic resonance imaging in detecting spinal metastases. J Nucl Med. 34(12):2191-8, 1993 Dec.

100. Venkitaraman R, Cook GJ, Dearnaley DP, et al. Does magnetic resonance imaging of the spine have a role in the staging of prostate cancer?. Clin Oncol (R Coll Radiol). 21(1):39-42, 2009 Feb.

101. Alexandru D, So W. Evaluation and management of vertebral compression fractures. [Review]. Permanente Journal. 16(4):46-51, 2012Fall.

102. Liang Y, Liu P, Jiang LB, et al. Value of CT-guided Core Needle Biopsy in Diagnosing Spinal Lesions: A Comparison Study. Orthop Surg. 11(1):60-65, 2019 Feb.

103. Patel U, Skingle S, Campbell GA, Crisp AJ, Boyle IT. Clinical profile of acute vertebral compression fractures in osteoporosis. Br J Rheumatol. 1991; 30(6):418-421.

104. Silverman SL. The clinical consequences of vertebral compression fracture. Bone. 1992; 13 Suppl 2:S27-31.

105. Ploeg WT, Veldhuizen AG, The B, Sietsma MS. Percutaneous vertebroplasty as a treatment for osteoporotic vertebral compression fractures: a systematic review. [Review] [56 refs]. Eur Spine J. 15(12):1749-58, 2006 Dec.

106. Voormolen MH, Mali WP, Lohle PN, et al. Percutaneous vertebroplasty compared with optimal pain medication treatment: short-term clinical outcome of patients with subacute or chronic painful osteoporotic vertebral compression fractures. The VERTOS study. AJNR Am J Neuroradiol. 2007; 28(3):555-560.

107. Anselmetti GC, Bernard J, Blattert T, et al. Criteria for the appropriate treatment of osteoporotic vertebral compression fractures. Pain physician. 16(5):E519-30, 2013 Sep-Oct.

108. Rousing R, Andersen MO, Jespersen SM, Thomsen K, Lauritsen J. Percutaneous vertebroplasty compared to conservative treatment in patients with painful acute or subacute osteoporotic vertebral fractures: three-months follow-up in a clinical randomized study. Spine (Phila Pa 1976). 2009; 34(13):1349-1354.

109. Parreira PCS, Maher CG, Megale RZ, March L, Ferreira ML. An overview of clinical guidelines for the management of vertebral compression fracture: a systematic review. [Review]. Spine J. 17(12):1932-1938, 2017 12.

110. Papaioannou A, Adachi JD, Winegard K, et al. Efficacy of home-based exercise for improving quality of life among elderly women with symptomatic osteoporosis-related vertebral fractures. Osteoporos Int. 14(8):677-82, 2003 Aug.

111. Sinaki M, Itoi E, Wahner HW, et al. Stronger back muscles reduce the incidence of vertebral fractures: a prospective 10 year follow-up of postmenopausal women. Bone. 30(6):836-41, 2002 Jun.

112. Georgy BA.. Metastatic spinal lesions: state-of-the-art treatment options and future trends. [Review] [40 refs]. AJNR Am J Neuroradiol. 29(9):1605-11, 2008 Oct.

113. Kallmes DF, Comstock BA, Heagerty PJ, et al. A randomized trial of vertebroplasty for osteoporotic spinal fractures. N Engl J Med. 2009; 361(6):569-579.

114. Buchbinder R, Osborne RH, Ebeling PR, et al. A randomized trial of vertebroplasty for painful osteoporotic vertebral fractures. N Engl J Med. 2009; 361(6):557-568.

115. Klazen CA, Lohle PN, de Vries J, et al. Vertebroplasty versus conservative treatment in acute osteoporotic vertebral compression fractures (Vertos II): an open-label randomised trial. Lancet. 2010; 376(9746):1085-1092.

116. Rousing R, Hansen KL, Andersen MO, Jespersen SM, Thomsen K, Lauritsen JM. Twelve-months follow-up in forty-nine patients with acute/semiacute osteoporotic vertebral fractures treated conservatively or with percutaneous vertebroplasty: a clinical randomized study. Spine (Phila Pa 1976). 2010; 35(5):478-482.

117. Wardlaw D, Cummings SR, Van Meirhaeghe J, et al. Efficacy and safety of balloon kyphoplasty compared with non-surgical care for vertebral compression fracture (FREE): a randomised controlled trial. Lancet. 2009; 373(9668):1016-1024.

118. Kanayama M, Oha F, Iwata A, Hashimoto T. Does balloon kyphoplasty improve the global spinal alignment in osteoporotic vertebral fracture?. International Orthopaedics. 39(6):1137-43, 2015 Jun.

119. Bouza C, Lopez T, Magro A, Navalpotro L, Amate JM. Efficacy and safety of balloon kyphoplasty in the treatment of vertebral compression fractures: a systematic review. [Review] [60 refs]. Eur Spine J. 15(7):1050-67, 2006 Jul.

120. Noriega DC, Kruger A, Ramajo RH, Ardura F, Munoz M, Sahin S. Long-Term Benefits of Percutaneous Anatomical Restoration of Vertebral Compression Fractures Linked to Malignancy. Turkish Neurosurgery. 26(4):608-14, 2016.

121. Yokoyama K, Kawanishi M, Yamada M, et al. In not only vertebroplasty but also kyphoplasty, the resolution of vertebral deformities depends on vertebral mobility. Ajnr: American Journal of Neuroradiology. 34(7):1474-8, 2013 Jul.

122. Yokoyama K, Kawanishi M, Yamada M, et al. Postoperative change in sagittal balance after Kyphoplasty for the treatment of osteoporotic vertebral compression fracture. European Spine Journal. 24(4):744-9, 2015 Apr.

123. Dong R, Chen L, Gu Y, et al. Improvement in respiratory function after vertebroplasty and kyphoplasty. Int Orthop. 33(6):1689-94, 2009 Dec.

124. Lee JS, Kim KW, Ha KY. The effect of vertebroplasty on pulmonary function in patients with osteoporotic compression fractures of the thoracic spine. Journal of Spinal Disorders & Techniques. 24(2):E11-5, 2011 Apr.

125. Yang EZ, Xu JG, Huang GZ, et al. Percutaneous Vertebroplasty Versus Conservative Treatment in Aged Patients With Acute Osteoporotic Vertebral Compression Fractures: A Prospective Randomized Controlled Clinical Study. Spine. 41(8):653-60, 2016 Apr.

126. Noriega D, Marcia S, Theumann N, et al. A prospective, international, randomized, noninferiority study comparing an implantable titanium vertebral augmentation device versus balloon kyphoplasty in the reduction of vertebral compression fractures (SAKOS study). Spine J. 19(11):1782-1795, 2019 11.

127. Cianfoni A, Distefano D, Isalberti M, et al. Stent-screw-assisted internal fixation: the SAIF technique to augment severe osteoporotic and neoplastic vertebral body fractures. J Neurointerv Surg. 11(6):603-609, 2019 Jun.

128. Pneumaticos SG, Chatziioannou SN, Savvidou C, Pilichou A, Rontogianni D, Korres DS. Routine needle biopsy during vertebral augmentation procedures. Is it necessary?. European Spine Journal. 19(11):1894-8, 2010 Nov.

129. Venturi C, Barbero S, Tappero C, et al. Coaxial biopsy during percutaneous vertebroplasty in patients with presumed osteoporotic vertebral compression fractures: retrospective review of biopsy results. Radiologia Medica. 116(2):302-9, 2011 Mar.

130. Lehman RA Jr, Kang DG, Wagner SC. Management of osteoporosis in spine surgery. [Review]. J Am Acad Orthop Surg. 23(4):253-63, 2015 Apr.

131. Lin CC, Shen WC, Lo YC, et al. Recurrent pain after percutaneous vertebroplasty. [Review] [62 refs]. AJR Am J Roentgenol. 194(5):1323-9, 2010 May.

132. Chen LH, Hsieh MK, Liao JC, et al. Repeated percutaneous vertebroplasty for refracture of cemented vertebrae. Arch Orthop Trauma Surg. 131(7):927-33, 2011 Jul.

133. Firanescu CE, de Vries J, Lodder P, et al. Vertebroplasty versus sham procedure for painful acute osteoporotic vertebral compression fractures (VERTOS IV): randomised sham controlled clinical trial. BMJ. 361:k1551, 2018 05 09.

134. Zhang H, Xu C, Zhang T, Gao Z, Zhang T, Does Percutaneous Vertebroplasty or Balloon Kyphoplasty for Osteoporotic Vertebral Compression Fractures Increase the Incidence of New Vertebral Fractures? A Meta-Analysis. [Review]. Pain physician. 20(1):E13-E28, 2017 Jan-Feb.

135. Kawaguchi S, Horigome K, Yajima H, et al. Symptomatic relevance of intravertebral cleft in patients with osteoporotic vertebral fracture. J Neurosurg Spine. 13(2):267-75, 2010 Aug.

136. Ryu CW, Han H, Lee YM, Lim MK. The intravertebral cleft in benign vertebral compression fracture: the diagnostic performance of non-enhanced MRI and fat-suppressed contrast-enhanced MRI. Br J Radiol. 82(984):976-81, 2009 Dec.

137. Kim JM, Losina E, Bono CM, et al. Clinical outcome of metastatic spinal cord compression treated with surgical excision +/- radiation versus radiation therapy alone: a systematic review of literature. [Review]. Spine. 37(1):78-84, 2012 Jan 01.

138. Babayev M, Lachmann E, Nagler W. The controversy surrounding sacral insufficiency fractures: to ambulate or not to ambulate?. [Review] [59 refs]. Am J Phys Med Rehabil. 79(4):404-9, 2000 Jul-Aug.

139. Dittmer DK, Teasell R. Complications of immobilization and bed rest. Part 1: Musculoskeletal and cardiovascular complications. [Review] [48 refs]. Can Fam Physician. 39:1428-32, 1435-7, 1993 Jun.

140. Masala S, Magrini A, Taglieri A, et al. Chronic obstructive pulmonary disease (COPD) patients with osteoporotic vertebral compression fractures (OVCFs): improvement of pulmonary function after percutaneous vertebroplasty (VTP). European Radiology. 24(7):1577-85, 2014 Jul.

141. Otten LA, Bornemnn R, Jansen TR, et al. Comparison of balloon kyphoplasty with the new Kiva VCF system for the treatment of vertebral compression fractures. Pain Physician. 16(5):E505-12, 2013 Sep-Oct.

142. Klimo P Jr, Schmidt MH. Surgical management of spinal metastases. [Review] [80 refs]. Oncologist. 9(2):188-96, 2004.

143. Khan MA, Deib G, Deldar B, Patel AM, Barr JS. Efficacy and Safety of Percutaneous Microwave Ablation and Cementoplasty in the Treatment of Painful Spinal Metastases and Myeloma. AJNR Am J Neuroradiol. 39(7):1376-1383, 2018 07.

144. Hillen TJ, Anchala P, Friedman MV, Jennings JW. Treatment of metastatic posterior vertebral body osseous tumors by using a targeted bipolar radiofrequency ablation device: technical note. Radiology. 273(1):261-7, 2014 Oct.

145. Tomasian A, Jennings JW. Vertebral Metastases: Minimally Invasive Percutaneous Thermal Ablation. [Review]. Tech Vasc Interv Radiol. 23(4):100699, 2020 Dec.

146. Wallace AN, Tomasian A, Vaswani D, Vyhmeister R, Chang RO, Jennings JW. Radiographic Local Control of Spinal Metastases with Percutaneous Radiofrequency Ablation and Vertebral Augmentation. AJNR Am J Neuroradiol. 37(4):759-65, 2016 Apr.

147. Tomasian A, Jennings JW. Hot and Cold Spine Tumor Ablations. [Review]. Neuroimaging Clin N Am. 29(4):529-538, 2019 Nov.

148. Berenson J, Pflugmacher R, Jarzem P, et al. Balloon kyphoplasty versus non-surgical fracture management for treatment of painful vertebral body compression fractures in patients with cancer: a multicentre, randomised controlled trial. Lancet Oncol. 2011; 12(3):225-235.

149. Cotten A, Dewatre F, Cortet B, et al. Percutaneous vertebroplasty for osteolytic metastases and myeloma: effects of the percentage of lesion filling and the leakage of methyl methacrylate at clinical follow-up. Radiology. 200(2):525-30, 1996 Aug.

150. Fisher CG, DiPaola CP, Ryken TC, et al. A novel classification system for spinal instability in neoplastic disease: an evidence-based approach and expert consensus from the Spine Oncology Study Group. [Review]. Spine. 35(22):E1221-9, 2010 Oct 15.

151. National Institute for Health and Care Excellence. Metastatic spinal cord compression in adults: risk assessment, diagnosis and management. 2008; Available at: https://www.nice.org.uk/guidance/cg75.

152. George R, Jeba J, Ramkumar G, Chacko AG, Tharyan P. Interventions for the treatment of metastatic extradural spinal cord compression in adults. [Review][Update of Cochrane Database Syst Rev. 2008;(4):CD006716; PMID: 18843728]. Cochrane Database Syst Rev. (9)CD006716, 2015 Sep 04.

153. Fourney DR, Gokaslan ZL. Anterior approaches for thoracolumbar metastatic spine tumors. [Review] [32 refs]. Neurosurg Clin N Am. 15(4):443-51, 2004 Oct.

154. Patchell RA, Tibbs PA, Regine WF, et al. Direct decompressive surgical resection in the treatment of spinal cord compression caused by metastatic cancer: a randomised trial. Lancet. 366(9486):643-8, 2005 Aug 20-26.

155. Dong L, Tan M, Wu D, et al. Palliative Surgery for Spinal Metastases Using Posterior Decompression and Fixation Combined With Intraoperative Vertebroplasty. Clin Spine Surg. 30(8):343-349, 2017 Oct.

156. Lutz S, Berk L, Chang E, et al. Palliative radiotherapy for bone metastases: an ASTRO evidence-based guideline. [Review]. Int J Radiat Oncol Biol Phys. 79(4):965-76, 2011 Mar 15.

157. Tong D, Gillick L, Hendrickson FR. The palliation of symptomatic osseous metastases: final

results of the Study by the Radiation Therapy Oncology Group. Cancer. 50(5):893-9, 1982 Sep 01.

158. Maranzano E, Latini P. Effectiveness of radiation therapy without surgery in metastatic spinal cord compression: final results from a prospective trial. Int J Radiat Oncol Biol Phys. 32(4):959-67, 1995 Jul 15.

159. Wu AS, Fourney DR. Evolution of treatment for metastatic spine disease. [Review] [67 refs]. Neurosurg Clin N Am. 15(4):401-11, 2004 Oct.

160. Palma DA, Olson R, Harrow S, et al. Stereotactic Ablative Radiotherapy for the Comprehensive Treatment of Oligometastatic Cancers: Long-Term Results of the SABR-COMET Phase II Randomized Trial. J Clin Oncol 2020;38:2830-38.

161. Zeng KL, Tseng CL, Soliman H, Weiss Y, Sahgal A, Myrehaug S. Stereotactic Body Radiotherapy (SBRT) for Oligometastatic Spine Metastases: An Overview. [Review]. Front. oncol.. 9:337, 2019.

162. Sahgal A, Myrehaug SD, Siva S, et al. Stereotactic body radiotherapy versus conventional external beam radiotherapy in patients with painful spinal metastases: an open-label, multicentre, randomised, controlled, phase 2/3 trial. Lancet Oncol. 22(7):1023-1033, 2021 07.

163. Chen X, Gui C, Grimm J, et al. Normal tissue complication probability of vertebral compression fracture after stereotactic body radiotherapy for de novo spine metastasis. Radiother Oncol. 150:142-149, 2020 09.

164. Wardak Z, Bland R, Ahn C, et al. A Phase 2 Clinical Trial of SABR Followed by Immediate Vertebroplasty for Spine Metastases. Int J Radiat Oncol Biol Phys. 104(1):83-89, 2019 05 01.

165. Redmond KJ, Lo SS, Fisher C, Sahgal A. Postoperative Stereotactic Body Radiation Therapy (SBRT) for Spine Metastases: A Critical Review to Guide Practice. [Review]. Int J Radiat Oncol Biol Phys. 95(5):1414-1428, 2016 08 01.

166. Lewington VJ.. Bone-seeking radionuclides for therapy. [Review] [75 refs]. J Nucl Med. 46 Suppl 1:38S-47S, 2005 Jan.

167. Finlay IG, Mason MD, Shelley M. Radioisotopes for the palliation of metastatic bone cancer: a systematic review. [Review] [74 refs]. Lancet Oncol. 6(6):392-400, 2005 Jun.

168. Bigos SJ, Bowyer OR, Braen GR, et al. Acute Low Back Problems in Adults. Clinical Practice Guideline No. 14. AHCPR Publication No. 95-0642. Rockville, MD: Agency for Health Care Policy and Research, Public Health Service, U.S. Department of Health and Human Services. December 1994. Available at: http://d4c2.com/d4c2-000038.htm.

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influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.

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