■ REVIEW ARTICLE

# Percutaneous vertebroplasty and balloon kyphoplasty for the treatment of osteoporotic vertebral compression fractures and osteolytic tumours

**A. G. Hadjipavlou,**
**M.N.Tzermiadianos,**
**P. G. Katonis,**
**M. Szpalski**

*From the University Hospital of Crete, Heraklion, Crete, Greece*

Back pain is the principal manifestation of most osteoporotic vertebral compression fractures, and may be either acute and excruciating, or chronic and persistent.[1,2] Acute back pain, usually caused by a recent osteoporotic vertebral compression fracture, is expected to subside as the fracture heals, over a period of approximately three months.[3] However, it is estimated that one-third[4] to three-quarters[5] of such patients may then develop chronic back pain. The causes may be attributed to pseudarthrosis or to osteoporotic spinal deformity such as kyphosis or kyphoscoliosis engendering a kaleidoscope of problems. The degree of kyphosis correlates well with the patient's physical function, the risk of further fractures,[6,7] compression of the spinal cord, mental well-being and pulmonary function,[8] any of which may contribute to an increased mortality rate.[7,9,10] Conservative treatment cannot address the deformity. Major reconstructive surgery is indicated for crippling deformity and for neurocompression.[11]

Percutaneous vertebroplasty was designed and introduced for the management of osteolytic tumours,[12-15] and later was successfully applied to osteoporotic vertebral compression fractures.[4,16-18] It has also been shown to be valuable in the treatment of osteogenesis imperfecta,[19] and has been used for focal Paget's disease of the spine refractory to medical treatment.[20] The technique is well described in the literature.[15,17,21,22]

Percutaneous balloon kyphoplasty is a more recent technique which applies the principles of balloon angioplasty to vertebroplasty. It was primarily devised for the treatment of osteoporotic vertebral compression fractures, and subsequently used in the treatment of metastatic osteolytic tumours.[23-25]

## Methodology of review

We have carried out a systematic review of work published between 1983 and September 2004. Of the 241 published studies (p), 146 were considered to be suitable for the present study (ps), based on complete data on outcome, complications, specific indications, case reports of rare complications and biomechanical and research studies. We found 38 case reports and accepted 23 for this study, eight case series for percutaneous vertebroplasty which were prospective but not randomised and 45 case series reviewed retrospectively. We also included case series of percutaneous balloon kyphoplasty as follows: prospective non-randomised (p = 17, ps = 17) and retrospective studies (p = 7, ps = 7). We have included comparison studies as follows: between percutaneous vertebroplasty and percutaneous balloon kyphoplasty (retrospective, p = 1, ps = 1), between percutaneous vertebroplasty and conservative treatment (prospective, non-randomised, p = 1, ps = 1), between percutaneous balloon kyphoplasty and conservative treatment (prospective non-randomised, p = 2, ps = 2, and retrospective, p = 1, ps = 1). Many review articles and personal communications (p = 77, ps = 5), and biomechanical and basic research papers (p = 39, ps = 31) have been published. Finally, studies on radiation exposure during fluoroscopy have been reported (p = 5, ps = 5).

Studies have been combined in order to compare percutaneous vertebroplasty with percutaneous balloon kyphoplasty using meta-regression techniques (random effects logistic regression, treating procedure type - percutaneous vertebroplasty *versus* percutaneous balloon kyphoplasty as a fixed and as a random effect). The comparison was extremely difficult, or in some cases impossible, because of the different tools and standards which were employed.

## Selection of patients

It is important to distinguish pain caused by a vertebral compression fracture from other causes of back pain. This requires a careful correlation of the patient's history with clinical examination and available imaging.

■ A. G. Hadjipavlou, MD, Professor and Chairman
■ M. N. Tzermiadianos, MD, Orthopaedic Surgeon
■ P. G. Katonis, MD, Assistant Professor
Department of Orthopaedics
University Hospital of Crete, P. O. Box 1352, Heraklion 71110, Crete, Greece.

■ M. Szpalski, MD, Associate Professor and Chairman
Department of Orthopaedics
Iris South Teaching Hospitals, Brussels, Belgium.

Correspondence should be sent to Dr A. G. Hadjipavlou; e-mail: ahadjipa@med.uoc.gr


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**Table I.** Efficacy of vertebroplasty in reducing pain in osteoporotic vertebral compression fracture (OVCF) and osteolytic metastatic tumours

| Authors | Number of patients | Number of vertebral bodies | Indication | Patients with good to excellent pain response* (%) | Pain reduction (visual analogue scale) | Study design† |
|---|---|---|---|---|---|---|
| **OVCF series** | | | | | | |
| Jensen et al[17] | 29 | 47 | OVCF | *90* | | Retro |
| Martin et al[98] | 9 | NR | OVCF | *77.7* | | Retro |
| Cortet et al[18] | 16 | 20 | OVCF | *88* | -6 | Prosp |
| Cyteval et al[4] | 20 | 23 | OVCF | *90* | | Prosp |
| O'Brien et al[42] | 6 | 6 | OVCF | *83.3* | | Retro |
| Barr et al[99] | 38 | 70 | OVCF | *95* | | Retro |
| Grados et al[36] | 25 | 34 | OVCF | *96* | -4.3 | Retro |
| Heini et al[52] | 17 | 45 | OVCF | *100* | -4.30 | Prosp |
| Maynard et al[100] | 27 | 35 | OVCF | *93* | -7.4 | Retro |
| Amar et al[101] | 97 | 258 | OVCF | *63* | | Retro |
| Moreland, Landi and Grand[102] | 35 | 53 | OVCF | *89* | | Retro |
| Kaufmann et al[103] | 75 | 122 | OVCF | | -7.5 | Retro |
| McGraw et al[56] | 100 | 156 | OVCF | *97* | -6.9 | Prosp |
| Peh, Gilula and Peck[104] | 37 | 48 | OVCF | *97* | | Retro |
| Kallmes et al[54] | 41 | 63 | OVCF (T4 to T8) | | -8 | Retro |
| Zoarski et al[105] | 30 | 54 | OVCF | *96* | | Prosp |
| Gaughen et al[62] | 48 | 84 | OVCF | *95.2* | -7.6 | Retro |
| Nakano et al[106] | 16 | 17 | OVCF | *100* | -7.73 | Retro |
| Ryu et al[59] | 159 | 347 | OVCF | *87* | | Retro |
| Perez-Higueras et al[107] | 13 | 27 | OVCF | *92.3* | -8 | Prosp |
| Evans et al[43] | 245 | 554 | OVCF | | -5.5 | Retro |
| Jang et al[47]‡ | 16 | 16 | OVCF | *88* | -4.7 | Retro |
| Diamond et al[37] | 55 | 71 | OVCF | *96.3* | | Prosp |
| Peh et al[29]† | 18 | 19 | OVCF | *77.7* | | Retro |
| Gangi et al[108] | 187 | 289 | OVCF | *78* | | Retro |
| Brown et al[34] | 41 | } 186 | OVCF > 1 year | *80* | | Retro |
| | 49 | | OVCF < 1 year | *92* | | |
| Chen et al[109] | 70 | 87 | OVCF | *85.5* | -4.4 | Retro |
| Winking et al[110] | 38 | 66 | OVCF | *92* | -5.2 | Prosp |
| Legroux-Gerot et al[73] | 16 | 21 | OVCF | *75* | -3.5 | Prosp |
| Total | 1573 | 2818 | | Mean *90* (86.1 to 92.8) | | |
| **Tumour series** | | | | | | |
| Weill et al[51] | 37 | 52 | Tumours | *94* | | Retro |
| Cotten et al[15] and Cortet et al[111] | 37 | 40 | Tumours | *97.3* | | Retro |
| Martin et al[98] | 20 | NR | Tumours | *65* | | Retro |
| Barr et al[99] | 8 | 13 | Tumours | *50* | | Retro |
| Fourney et al[25] | 34 | 65 | Tumours | *86* | | Retro |
| Winking et al[112] | 28 | | Tumours | *83* | | Prosp |
| Alvarez et al[41] | 21 | 27 | Tumours | *81* | -6.30 | Retro |
| Total | 185 | 197 | | Mean *86.2* (75.9 to 92.5) | | |
| **OVCF + tumour series** | | | | | | |
| Kim et al[113] | 49 | 75 | OVCF + tumours | *90* | | Retro |
| Mousavi et al[58] | 21 | 33 | OVCF + tumours | | -6.3 | Retro |
| Hodler, Peck and Gilula[114] | 152 | 363 | OVCF + tumours | *86.1* | | Retro |
| Total | 222 | 471 | | Mean *90.7* (76.5 to 96.7) | | |

* in this and other tables, meta-analytic responses are summarised with random effects meta-analysis/logistic regression using SAS GLIMMIX macro (SAS Version 8.2, Cary, North Carolina). Study was the random effect and indication the fixed effect

† Retro, retrospective; Prosp, prospective

‡ only OVCF with pseudarthrosis

**Clinical assessment.** Local tenderness as a principal sign of symptomatic fracture of a vertebral body was analysed in two studies. Gaitanis et al[26] found that tenderness over the spinous process corresponding to the level of the pathology was elicited in 100% of osteolytic tumours, and in 96% of compression fractures when correlated with MR findings of an acute fracture. On the other hand, Gaughen et al[27] noted that local tenderness was not present in ten patients with findings on imaging suggestive of an acute fracture.

**Imaging modalities.** Flexion/extension or standing/supine lateral radiographs can reveal mobile fractures, particularly fresh fractures or pseudarthroses which are capable of postural correction by extension of the spine. Intravertebral clefts characterising pseudarthrosis can easily be missed when examining standing lateral radiographs since they may be seen in as few as 14% of pseudarthrotic vertebral bodies compared with 64% detectable by supine, cross-table radiography.[28] Peh et al,[29] in a retrospective study of lateral radiographs, reported vacuum phenomena in 9% of patients (4.8% of the vertebral compression fractures) reflecting the poor sensitivity of lateral radiographs in detecting intravertebral clefts. In regard to the latter,

**Table II**. Efficacy of kyphoplasty in reducing pain in osteoporotic vertebral compression fracture (OVCF) and osteolytic metastatic tumours

| Authors | Number of patients | Number of vertebral bodies | Indication | Patients with good to excellent pain response (%) | Pain reduction (visual analogue scale) | Study design* |
|---|---|---|---|---|---|---|
| **OVCF series** | | | | | | |
| Theodorou et al[115] | 15 | 24 | OVCF | *100* | | Retro |
| Wong et al[116] | 85 | 143 | OVCF | *94* | | Retro |
| Wilhelm et al[117] | 34 | 56 | OVCF | | -4.3 | Prosp |
| Phillips et al[50] | 29 | 61 | OVCF | *96.6* | -8 | Prosp |
| Crandall et al[33] | 23 | 40 | Acute OVCF | *90* | -3 | Prosp |
| | 24 | 46 | Chronic OVCF | *87* | | Prosp |
| Berlemann et al[35] | 24 | 27 | OVCF | *96* | -6.9 | Retro |
| Hillmeier et al[118] | 102 | 192 | OVCF | *89* | | Prosp |
| Gaitanis et al[26] | 27 | 49 | OVCF | *96.5* | | Prosp |
| Total | 363 | 638 | | Mean *93.6* (88.2 to 96.6) | | |
| **Tumour series** | | | | | | |
| Dudeney et al[24] | 18 | 55 | MM† | *100* | | Prosp |
| Fourney et al[25] | 15 | 32 | Tumours | *80* | | Retro |
| Gaitanis et al[26] | 5 | 12 | Tumours | *100* | -7 | Prosp |
| Total | 38 | 99 | | Mean *92.8* (75.6 to 98.2) | | |
| **OVCF + tumour series** | | | | | | |
| Lieberman et al[23] | 30 | 70 | OVCF + MM | *100* | | Prosp |
| Garfin et al[57] | 340 | 603 | OVCF + tumours | 90 | | Prosp‡ |
| Ledlie and Renfro[44] | 96 | 133 | OVCF + tumours | *98* | -7.20 | Retro |
| Coumans et al[72] | 78 | 188 | OVCF + MM | | -3.6 | Prosp |
| Weisskopf et al[38] | 22 | 37 | OVCF + tumours | | -6.7 (*82*) | Retro |
| Rhyne et al[119] | 52 | 82 | OVCF + tumours | | -6.26 | Retro |
| Total | 618 | 1113 | | Mean *95.6* (89.1 to 98.3) | | |

* Retro, retrospective; Prosp, prospective
† MM, multiple myeloma
‡ prospective multicentre

MRI is more sensitive than plain radiography with a reported accuracy of 96%.[28] However, Lane et al,[30] in a retrospective analysis, reported intravertebral clefts in 31.8% of patients during percutaneous vertebroplasty, 52.8% of which had been detected on pre-operative MRI. By contrast, gas-filled clefts were seen in only 11.4% of pre-operative radiographs. MR is the most useful imaging technique for the detection of oedema indicating acute fracture. This is best depicted on sagittal MR images with short tau inversion recovery (STIR),[31,32] which is also a good predictor of correction of deformity with balloon kyphoplasty.[26]

When patients are unable to tolerate MRI, $^{99}$Tc-methyl-diphosphonate bone scanning combined with computer-assisted tomography can provide useful information on relatively fresh vertebral fractures. Bone scanning may remain negative in patients with vertebral fractures with minimal loss of height, or remain positive for a prolonged period of time (up to two years) after healing of a fracture, reflecting remodelling.

## Measurements of outcome

**Clinical response**. Both vertebroplasty and balloon kyphoplasty have been shown to be highly effective in reducing pain from both compression fractures and osteolytic tumours (Tables I and II). Most of the fractures treated are subacute and less than one year old. Although better results can be expected in more recent fractures, quite satisfactory results have been reported in chronic cases.[33,34] No correlation was found between the degree of correction of the vertebral body with balloon kyphoplasty[35] or the volume of cement injected,[15] and the clinical outcome.

Regarding the long-term effect of vertebroplasty on pain, Grados et al[36] reported good or excellent results in 96% of patients with a mean follow-up of 48 months (12 to 84). Diamond, Champion and Clark[37] in a prospective non-randomised study, compared the outcome of 55 patients who underwent percutaneous vertebroplasty, with that of 24 who declined the procedure. Although there was a dramatic improvement in pain and physical function in the vertebroplasty group by 24 hours, after six weeks no difference could be detected between the groups. However, in this study the comparison was made with patients who had declined the surgical procedure, imposing a strong bias on the results.

The studies listed in Tables I and II have been combined in order to compare vertebroplasty with balloon kyphoplasty using meta-regression techniques. The design of the study appeared to have a considerable impact on the analysis. For prospective studies, the rates of success of vertebroplasty and kyphoplasty were equivalent at 92% and 93% respectively (p = 0.6312). For retrospective studies, however, kyphoplasty appeared to be more successful (95% *vs* 86%; p = 0.019). Among retrospective studies, the success rates were higher when kyphoplasty was used for compression fractures and when compression fractures were combined with lytic tumours, but lower in the group of patients with lytic tumours alone.

There was only one study available[25] which directly compared vertebroplasty with kyphoplasty and this reported equivalent results in relieving pain. Unfortunately, this review is retrospective and is limited to patients with cancer. In the three studies which directly compared kyphoplasty with conventional medical treatment,[38-40] kyphoplasty consistently improved the levels of pain and physical function and the results were sustained at six months.

From the available data regarding the management of pain it appears that kyphoplasty has given slightly more favourable results than vertebroplasty, but this does not reach statistical significance. Clearly, kyphoplasty gives better results than conventional standard medical treatment.

A major benefit of vertebral augmentation surgery was the restoration of mobility in 73% of 11 wheelchair-bound patients with cancer treated by vertebroplasty.[41] In severely handicapped osteoporotic patients, restoration of mobility with vertebroplasty ranged from 80%[42] to 82%,[43] and with kyphoplasty from 84%[44] to 100%.[26]

**Restoration of vertebral height.** The possible beneficial effects of vertebroplasty are attributed either to postural reduction of a mobile vertebra by hyperextension, or to the injection of viscous cement under pressure. Movement of fragments has been reported in 44% of patients with compression fractures (35% of fractured vertebrae).[45] Most mobile fractures are seen at the thoracolumbar junction (81%).[46] Jang, Kim and Lee,[47] in a series of patients with single mobile fractures, reported that the mean anterior vertebral height, measured on the standing flexion radiographs before operation, improved from 14.8 mm to 21.8 mm with extension of the spine. After vertebroplasty the mean anterior height was 19.8 mm, suggesting that considerable reduction can be achieved by postural extension and preserved by vertebroplasty, with a slight loss of maximum correction (mean 2 mm). Teng et al[48] also reported that reduction is more pronounced in vertebrae seen to contain gas, with a mean wedge-angle reduction of 10.2°. However, Hiwatashi et al[49] found that no patients with a substantial increase in the height of the vertebral body showed fluid- or gas-filled clefts on pre-operative MR images. They attributed the increase in height to the injection of high-viscosity cement under pressure and noted that it was more obvious in vertebrae with intact bony walls which appeared to prevent leakage.

Some of the variation in the results reported in studies of balloon kyphoplasty may be influenced by the age of the fracture and the degree of deformity. All the reports agree that the age of the fracture is the major determinant in achieving a satisfactory reduction.[33,35] Some authors state that meaningful correction in height can be achieved in some fractures even older than three months,[26,33,35] which seems predictable in cases of pseudarthrosis. Others contradict this assertion.[50] Crandall et al[33] reported failure of significant correction in 20% of chronic as opposed to 8% of acute fractures. The ability to restore vertebral height also improves with the amount of pre-operative kyphosis, and in patients with a more caudal location of the fracture.[35] More data are needed to compare the two techniques in a prospective randomised fashion with a standardised and validated method.

## Complications

Complications associated with vertebroplasty or kyphoplasty can be ascribed to the procedure itself or to cardiac and pulmonary problems, which are less common than following open surgical procedures.

**Transient increase in pain.** A transient increase in pain during vertebroplasty has been described,[15,36,51] with an incidence varying between 4%[36] and 23.4%.[52] This may be attributed to an increase in pressure in a painful vertebra, to an inflammatory reaction to polymethylmethacrylate (PMMA) or to osseous ischaemia.[53]

**Infection.** Kallmes et al[54] described a case of infection with *Staphylococcus epidermidis* in a series of 41 patients treated by vertebroplasty for compression fracture. Yu et al[55] reported a case of osteomyelitis in a patient who underwent vertebroplasty one week after infection of the urinary tract. This suggests that concurrent infection is a contra-indication to both vertebroplasty and kyphoplasty.

**Rib and sternal fractures.** Rib fractures have been occasionally associated with vertebroplasty and kyphoplasty,[17,23,43] and fracture of the sternum has also been seen after vertebroplasty.[56]

Surgeons and theatre personnel should avoid leaning over these frail patients who require delicate handling.

**Technical complications.** Kallmes et al[54] described a fracture of the pedicle occurring after faulty placement of instruments in one patient in their series of 41, and Diamond et al[37] noted two fractures of the transverse process in 55 patients having vertebroplasty. Other technical complications from the inappropriate placement of instruments during balloon kyphoplasty, have resulted in a breach of the pedicle and inadvertent leakage of cement into the spinal canal, a post-operative haematoma in two patients and injury to the spinal cord when an extrapedicular approach was used on a vertebra with a fractured pedicle.[57] In these last three patients serious neurological complications developed, partial motor loss in the first two, and an anterior-cord syndrome in the third. Leakage of cement is the most serious potential complication.

Occasional rupture of the inflatable tamps during balloon kyphoplasty has been reported. In all instances the ruptured tamp was easily withdrawn without clinical consequences.[23,26]

**Leakage of cement.** Although leakage of cement is well tolerated in most cases, it is the main source of pulmonary and neurological complications. Reports of such leakage revealed on radiographs are less reliable than those reported by CT. It has been reported that extravasation of cement is more common when vertebroplasty is used for metastatic osteolytic tumours or myelomas. However, Vas-

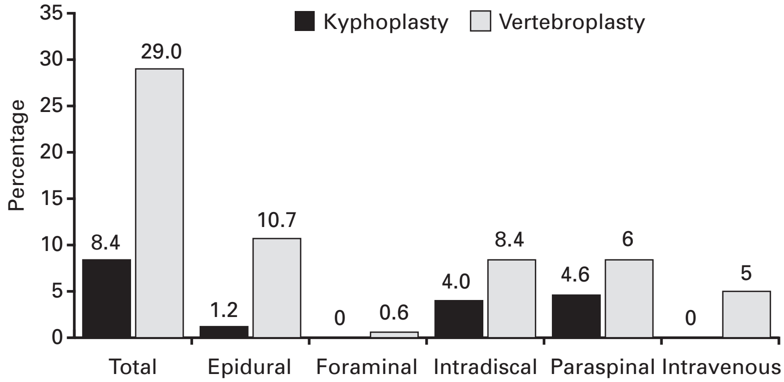


Fig. 1

Histogram depicting differences between kyphoplasty and percutaneous vertebroplasty in the percentage per location of cement extravasation. Cumulative data from 1279 vertebral bodies treated with kyphoplasty and 2729 vertebral bodies treated with vertebroplasty.

concelos et al[22] observed no major differences, although they noted venous leaks slightly more frequently in patients with metastatic lesions. When percutaneous vertebroplasty was performed for severely compressed vertebral bodies with fractured endplates, leakage from the disc space was more commonly observed.[22] Mousavi et al[58] reviewing post-operative CT scans in patients with compression fractures and metastatic tumours, concluded that in osteoporotic vertebrae leakage occurred mainly into the disc, whereas in metastatic lesions it was found in many areas.

In studies on vertebroplasty, epidural leakage of PMMA cement is reported to occur more often in levels above T7.[59] The risk of extravasation of cement into veins and into the epidural space increases with the volume of the cement injected.[59] Some authors advise against attempts to inject more than 5 ml of PMMA into one vertebra.[60] Although McGraw et al[56] found that intraosseous venography predicted the flow of PMMA during vertebroplasty in 83% of cases, this has not been confirmed by others, and the use of venography has largely been abandoned[61-63] except in hypervascular tumours. The viscosity of the cement has been shown to represent the most important factor in extravasation.[64] Heini et al[21] felt that the risk of intravascular extravasation is diminished if the flow of cement is directed medially. They suggested the use of a side-opening cannula.

Tsai et al[65] reported an anterior displacement of cement, one month after percutaneous vertebroplasty for a compression fracture with a fluid-filled intravertebral cleft at T12. Balloon kyphoplasty creates a cavity which allows a more viscous cement to be inserted slowly thereby decreasing the risk of extravasation. Inflation of the balloon compacts the trabecular bone, which may seal osseous defects or venous pathways. This hypothesis was confirmed by Phillips et al,[66] who injected contrast material before and after balloon inflation in 20 kyphoplasties for compression fracture. Fourney et al,[25] treating metastatic lesions, reported an incidence of 9% of leakage in vertebroplasty, but none in balloon kyphoplasty. Studies on cadavers also showed a reduced rate of leakage in kyphoplasty. Belkoff et al[67] noted extravertebral leakage of cement from five of eight fractured vertebral bodies in human cadavers treated by vertebroplasty, but no leakage during kyphoplasty.

These reports give strong evidence that kyphoplasty is safer than vertebroplasty (Fig. 1). The widely variable incidence of extravasation of cement during augmentation procedures, and the more accurate detection by CT, suggests that this complication is probably more common than is recognised.

### Clinical complications of leakage of cement

*Pulmonary embolism.* In an experimental sheep model, Aebli et al[68] demonstrated the potentially serious cardiovascular complications that can be caused by fat embolism during vertebroplasty, regardless of the augmentation material. Augmentation of more than one vertebral body is associated with a cumulative incidence of embolic phenomena. The reasons for these complications are mainly related to the increase in intraosseous pressure during augmentation, causing propulsion of bone-marrow contents into the circulation, or to reduction of the sympathetic tone, rather than to the methylmethacrylate monomer.[69] Placement of a needle as a vent in the contralateral pedicle has been advocated during the injection of cement.[70] In a retrospective study of 78 patients, Kaufmann et al[71] reported a significant but transient drop in oxygen saturation for ten minutes after vertebroplasty. There is only one reported case of non-fatal cement pulmonary embolism after kyphoplasty reported in the literature.[57]

Based on the recognised toxicity of PMMA when spilled into the venous circulation, some authors recommend that the maximum volume of injected cement should not exceed 30 ml or three levels per session.[72] However this may be excessively cautious in balloon kyphoplasty since the cement can be inserted in a very viscous state. In our series 11 patients underwent five levels and two six levels at the same sitting without untoward effects on the blood pressure or blood gases.

**Neurological complications.** Although leakage of cement into the spinal canal is well tolerated in most cases, it can occasionally lead to serious neurological complications and even paraplegia. Intraforamenal leakage is more harmful. Cotten et al[15] found that leakage from the spinal canal was well tolerated in all their 15 patients while two of eight cases of foraminal leakage were associated with radiculopathy. Transient femoral neuropathy have been reported after leakage of PMMA into the psoas muscle.[4,15] In most cases, however, the symptoms are transient and respond well to nerve-root blocks, or oral medication; rarely do they require surgical decompression.[4,15,51] From these reports it is apparent that kyphoplasty fares better than vertebroplasty in terms of neurological complications.

*Adjacent fractures.* A number of reports indicate an increased risk of secondary fractures adjacent to the augmented vertebra. The odds ratio for a vertebral fracture in the vicinity of a cemented vertebra has been reported to be between 3.18[73] and 2.27,[36] compared with 2.14[73] to 1.44[36] in the vicinity of an uncemented fracture. The greater the degree of augmentation of the treated vertebra and the location of the adjacent vertebra at the thoracolumbar junction are considered to be risks for secondary vertebral body fractures.[74]

Lin et al[75] found that 71.4% of patients with secondary fractures had intradiscal leakage of cement. In their study, vertebral bodies adjacent to a disc with leakage of cement had a 58% chance of developing a new fracture compared with 12% of vertebral bodies adjacent to a disc without leakage.[75] Leakage into the disc, by impeding the flexibility, may increase the risk of a secondary fracture in an adjacent vertebral body.

Analysis of the incidence of secondary fractures after vertebroplasty in the series of Lin et al[75] is made more difficult by lack of a mean period of follow-up. Assuming the mean to be about 12 months, and analysing for both numbers of patients and length of follow-up, random effects Poisson regression shows, on meta-analysis, a rate per patient-month of 0.82% (0.45% to 1.49%). Appropriate meta-analysis of such an incidence after kyphoplasty is difficult because of the lack of a mean follow-up period in two studies.

Lindsay et al[76] found a mean incidence of 19.2% of secondary vertebral fractures within one year of an initial vertebral fracture in patients with osteoporosis. In women with one previous fracture, the incidence was 11.5%, whereas 24% of the women with two or more fractures had a new fracture within the following year. Silverman et al[77] reported that 58% of women with one or more fractures had adjacent fractures.

A kyphotic deformity moves the centre of gravity forwards resulting in an increased forward bending moment which increases the load within the kyphotic angle and predisposes adjacent vertebrae to suffer secondary fractures. Reduction of deformity with kyphoplasty may be expected to decrease the risk of new fractures. This view is supported by two small, prospective, non-randomised studies which compared kyphoplasty with conservative treatment. In the first, Kasperk et al[40] found that at follow-up at six months, 30% of 20 patients who had been treated conservatively developed secondary fractures, compared with 12.5% of 40 patients who had undergone kyphoplasty. The incidence of fractures at adjacent levels was also reduced from 12% to 6%. Similarly, Komp et al[39] reported that at follow-up at six months, the incidence of new fractures in 17 conservatively-treated patients was 65% compared with 37% in 19 patients treated by kyphoplasty.

The rates of new fracture after cement augmentation procedures are not comparable between vertebroplasty (0% to 52%), kyphoplasty (5.8% to 36.8%) and conservatively-treated patients (19.2% to 58%), because of the poor scientific design of the studies. Most are retrospective or non-randomised prospective reports.

## Laboratory studies

It has been suggested that the increased strength of a vertebral body after vertebroplasty would lead to a greater risk of fracture of an adjacent vertebral body.[78,79] The biomechanical properties of various cement augmentations have been investigated. There is some variation between the value of compressive stiffness and strength, according to various investigators. The greater values described by Tomita et al[80] may be explained by the fact that the weak osteoporotic bone of the original vertebra will show a greater improvement in strength after kyphoplasty or vertebroplasty. Restoration of stiffness is reported to be loosely associated with the volume of cement injected,[81] and this may explain the discrepancies between various studies. Tomita et al[80] attributed the increased vertebral strength and decreased stiffness after kyphoplasty or vertebroplasty to the presence of cancellous bone remaining between the end-plate and bone cement. Sufficient cement should be injected between the end-plates and a plausible mechanical explanation for the disparity of the results among various investigators may be in the use of different volumes of cement.

Heini et al[82] and Tomita et al[80] observed that the lower the initial bone mineral density is, the more pronounced is the augmentation effect. In strong non-osteoporotic bone, cement augmentation does not produce any significant changes.[82] In cadavers, the amount of cement sufficient to restore the mid thoracic vertebral strength is between 2 ml[83] and 2.5 ml;[84] for the thoracolumbar spine, between 2.5 ml[84] and 4 ml[83] and for the lumbar spine 3.1 ml[84] to 6 ml.[83] To restore compressive stiffness, the quantity of cement was 4 ml for the thoracic spine according to two studies,[83,84] varying between 4 ml[84] and 8 ml[83] for the thoracolumbar region, and 8 ml[84] for the lumbar region. Liebschner, Rosenberg and Keaveny[85] demonstrated that 14% of the volume of a vertebral body, or less than 3 ml of bone cement, are required to restore compressive stiffness in vertebroplasty. A quantity greater than 30% of the volume of a vertebral body will substantially increase compressive stiffness. Molloy et al[83] reported comparable measurements. Tohmeh et al[86] stated that unipedicular insertion of cement gives results comparable with those following a bipendicular approach; but, Liebschner et al[85] preferred the latter.

The optimal augmentation, yet to be quantified, would provide sufficient local strength and stiffness without predisposing to fracture of adjacent vertebrae.

## Exposure to radiation

During vertebroplasty, radiation doses of 0.022 to 3.256 mGy outside and 0.01 to 0.47 mGy inside the lead apron have been reported.[87] The dose on the operator's hand ranged between 0.5 and 8.5 mGy indicating greater exposure to the operator's hands than expected from traditional apron measurement.[87]

Implementation of protective measures has been effective for reducing radiation.[87-89] When these were used, the mean whole-body dose for vertebroplasty was reduced from 1.44 to 0.004 mSv per vertebrae, and the mean hand dose from 2.04 mSv to 0.075 mSv per vertebrae. Tests of shielding devices indicate a significant reduction in whole-body and hand doses ranging from 42.9% to 86%.[89] The use of an injection instrument also significantly decreases the radiation dose to the operator's hands.[90]

A recent report[91] indicated that the mean total fluoroscopy time for kyphoplasty was 10.1 minutes (SD 2.2). The mean effective patient dose was 8.5 to 12 mSv, and the mean gonadal dose 0.04 to 16.4 mGy, depending on the level of the treated vertebrae. Skin damage after percutaneous kyphoplasty is improbable if the source-to-skin distance is 35 cm or more. However, problems may occur if the total fluoroscopy time per projection is extended and/or the source-to-skin distance during the procedure is less than 35 cm.

## Overview

Osteoporosis is not a benign process of ageing, but is associated with variety of disabling symptoms, ranging from mild local discomfort to crippling spinal deformity, occasionally associated with serious neurological deficits and even paraplegia.[11] As life expectancy continues to increase, vertebral compression fractures and metastatic osteolytic lesions will become an expanding health problem with enormous socio-economic costs.[92] The indication for the surgical management should not be limited to pain, but should also address the spinal deformity. Since more reliable and complete reduction is achieved with early treatment, Yuan, Brown and Phillips[93] have argued for prompt intervention. In patients with spinal metastases, cement augmentation provides immediate and substantial relief from pain, restores the osseous defect and structural strength of the collapsed vertebrae, particularly in kyphoplasty, and does not delay treatment with radiotherapy or chemotherapy. These benefits, quite apart from the relief from pain, should also be considered a strong argument for the prompt management of metastatic osteolytic tumours of the spine.

Although postural reduction can improve the vertebral height following a compression fracture, better results are obtained with kyphoplasty and vertebroplasty cannot be accepted as a safe technique. Radiological methods for measurement of the vertebral body height are imprecise and do not assess the global vertebral deformity.[94] The data on restoration of the height of the vertebral body in both techniques are muddled because of the different methods used for assessment.[95] Restoration of the sagittal alignment of the spine will bring about a change of the displaced centre of gravity backwards, thereby decreasing the risk for secondary fractures. The creation of a void within the vertebral body surrounded by impacted trabeculae allows the insertion of viscous bone cement with moderate pressure, obviating leakage of cement.

A disadvantage of kyphoplasty is the high cost of the equipment.[96,97] The procedure takes longer and is more painful than vertebroplasty, usually requiring general anaesthesia and more irradiation.

## Conclusions

Both percutaneous vertebroplasty and balloon kyphoplasty have been shown to be effective in controlling pain and improving function. Similar results have also been obtained in the treatment of osteolytic tumours. Kyphoplasty has the advantage of improving or restoring the vertebral height and kyphotic deformity. However, approximately one-third of osteoporotic vertebral compression fractures are mobile. Satisfactory reduction can be achieved by hyperextending the patient's spine on the operating table and using kyphoplasty to maintain the reduction.

Leakage of cement, rare after kyphoplasty, seems to be a common complication of vertebroplasty. It is well tolerated in most cases but it can lead to serious neurological and pulmonary complications. Augmentation of the vertebral body by PMMA cement restores the strength and increases the stiffness of the vertebrae and may predispose the adjacent vertebral bodies to new fractures.

The ideal amount of augmentation necessary to restore a desirable degree of local strength and stiffness has not been established.

## Supplementary Material

Tables showing a comparison of studies between balloon kyphoplasty and percutaneous vertebroplasty, the mean restoration of height after balloon kyphoplasty and percutaneous vertebroplasty, the incidence and location of cement leakage during balloon kyphoplasty and percutaneous vertebroplasty, the reported cases of pulmonary embolism during cement augmentation procedures, the neurological complications after percutaneous vertebroplasty, the incidence of vertebral body fractures after balloon kyphoplasty and percutaneous vertebroplasty and the biomechanical properties of bone-cement augmentation of vertebral bodies are available with the electronic version of this article on our website at www.jbjs.org.uk

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