■ ASPECTS OF CURRENT MANAGEMENT

The surgical management of metastatic epidural compression of the spinal cord

N. A. Quraishi,
Z. L. Gokaslan,
S. Boriani

*From Centre for
Spine Studies and
Surgery, Nottingham,
United Kingdom*

Metastatic epidural compression of the spinal cord is a significant source of morbidity in patients with systemic cancer. With improved oncological treatment, survival in these patients is improving and metastatic cord compression is encountered increasingly often. The treatment is mostly palliative. Surgical management involves early circumferential decompression of the cord with concomitant stabilisation of the spine. Patients with radiosensitive tumours without cord compression benefit from radiotherapy. Spinal stereotactic radiosurgery and minimally invasive techniques, such as vertebroplasty and kyphoplasty, with or without radiofrequency ablation, are promising options for treatment and are beginning to be used in selected patients with spinal metastases.

In this paper we review the surgical management of patients with metastatic epidural spinal cord compression.

The skeleton is the third most common site of metastases after the lungs and liver,¹ with the spinal column most frequently involved.¹ Post-mortem studies have shown that, depending on the histopathology of the primary site, 30% to 90% of patients with terminal cancer have metastatic spinal disease.^{2,3} Symptomatic metastatic spinal disease will become more prevalent as the rates of survival improve for many common cancers.

Metastatic epidural spinal cord compression (MESCC) is defined radiologically as an epidural metastatic lesion causing true displacement of the spinal cord from its normal position in the vertebral canal.⁴ It is estimated to occur in between 5% and 10% of patients with cancer, most commonly of the breast, prostate and lung, and in up to 40% of patients who have pre-existing bone metastases outside the spine.^{5,6}

There are approximately 25 000 cases of symptomatic MESCC annually in the United States.² Unfortunately, the incidence in the United Kingdom is uncertain because of the lack of a recognised coding system for diagnosis.⁷ Symptomatic spinal metastases may be the initial presentation in up to 10% of patients with cancer⁸ and pain is the most common symptom, occurring in between 83% and 95%.⁹ The pain may be local due to periosteal stretching from growth of the tumour and/or the local inflammatory process, mechanical as a result of instability or radicular from

irritation of a nerve root.¹⁰ Patients often present with a combination of these and there may be both myelopathic and radicular abnormalities. Approximately between 60% and 85% of patients have motor weakness at the time of diagnosis.¹⁰

Bladder dysfunction is the most common autonomic finding and commonly correlates with the degree of motor deficit.¹¹ Although the rate of clinical progression is variable, patients with motor weakness inevitably progress to complete paralysis in the absence of intervention.¹⁰ The neurological status at the time of diagnosis, particularly motor function, has been shown to correlate with the prognosis of MESCC,¹² reinforcing the concept that diagnosis before the development of a neurological deficit is of paramount importance. Levack et al,¹³ in a study of 319 patients, found that there was a median of two months from the onset of pain, as reported to the providers of primary care, to the diagnosis of metastatic spinal-cord compression. Therefore a new onset of back or neck pain in a patient with known cancer must be considered to be due to spinal metastatic disease until proven otherwise. Moreover, since thoracic pain is less common than that originating from the mobile cervical and lumbar regions, pain at this site should raise even greater suspicion.¹⁰

MRI remains the optimum method for assessing spinal metastatic disease¹⁴⁻¹⁶ and combined with CT for defining the osseous

■ N. A. Quraishi, FRCS,
Consultant Spinal Surgeon
Centre for Spine Studies and
Surgery
Queens Medical Centre, Derby
Road, Nottingham NG7 2UH,
UK.

■ Z. L. Gokaslan, MD, FACS,
Professor of Neurosurgery,
Oncology and Orthopaedic
Surgery
Department of Neurosurgery
Johns Hopkins University
School of Medicine, 600 North
Wolfe Street, Meyer 7-109
Baltimore, Maryland 21287,
USA.

■ S. Boriani, MD, Head of
Oncological and Degenerative
Spine Surgery
Rizzoli Institute, via Pupilli 1,
40136 Bologna, Italy.

Correspondence should be sent
to Mr N. A. Quraishi; e-mail:
nasquraishi@hotmail.com

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Fig. 1

Our algorithm for the surgical management of metastatic spinal cord compression. In rare circumstances, *en bloc* resection with the aim of curing the cancer may be used for confirmed solitary metastasis (and no epidural infiltration) following complete staging.

anatomy, is the most effective method of evaluating these patients. As the number of patients with MESCC increases, the methods of treatment are also evolving. Early methods of management focused on decompressive laminectomy followed by conventional radiotherapy, but studies later showed that the latter alone was more beneficial than the former. However, technological advances in spinal surgery have allowed more effective decompression of the spinal cord and stabilisation of the spine, and there is now a trend towards using more advanced surgical options rather than conventional radiotherapy. The guidelines of the National Institute for Clinical Excellence on metastatic cord compression have been published recently and provide recommendations on promoting best practice and preventing adverse outcomes in these patients.⁷ We now review the surgical management of MESCC.

Management

After a review of the literature, we have devised an algorithm which gives a framework for the surgical manage-

ment of symptomatic spinal metastases and MESCC (Fig. 1). Overall, a multidisciplinary approach involving specialists in oncology, haematology, histopathology, spinal surgery and radiology is required. The treatment of MESCC is primarily palliative with the aim of restoring or preserving neurological function, relieving pain and maintaining or restoring spinal stability.

Scoring systems. Various systems using a range of prognostic factors have been devised and correlated with the clinical outcome to predict survival. They allow the recognition of patients who are unlikely to do well after surgery and the choice of suitable management. Recognised systems include that of Tomita et al.¹⁷ and the revised scheme of Tokuhashi et al.¹⁸ The former uses three factors which have been shown to be significant, namely the grade of malignancy and the presence of visceral metastases and metastases in bone. The revised Tokuhashi scoring system¹⁸ additionally differentiates the primary site of the neoplasm and the influence of the neurological status to predict survival.

Non-operative management

Chemotherapy. Chemotherapeutic agents can be classified into anti-tumour drugs and those which minimise the secondary effects of the tumour.¹⁹ Except in tumours such as Ewing's sarcoma and neuroblastoma which are chemosensitive, anti-tumour drugs have a limited role in the treatment of spinal metastases. However, drugs which prevent or ameliorate the effects of spinal tumours, such as corticosteroids, bisphosphonates and analgesics, are widely used.

Corticosteroids are the mainstay of the pharmacological treatment of pain associated with spinal metastases and the acute neurological deterioration which may occur. They decrease oedema of the spinal cord and may have an oncolytic effect on certain tumours, such as lymphoma and breast cancer.²⁰ Observations on animal models have confirmed the clinical finding that individuals treated with dexamethasone achieve improved motor function more quickly than untreated control patients.¹⁹⁻²¹ The optimum dosing schedules for corticosteroids in patients with MESCC have not been determined prospectively. Indeed, it has been shown that there was no difference in outcome with regard to pain, walking or bladder function with the administration of an initial intravenous bolus of 100 mg compared with that of 10 mg.²²⁻²⁴ We give 16 mg of dexamethasone per day, in four individual doses of 4 mg, pre-operatively for five to seven days to patients with MESCC, except for those with a lymphoma, and then reduce the dose over five to seven days after operation. Bisphosphonates can be given orally or intravenously to inhibit osteoclastic activity. They do not prevent skeletal metastases, but are used to treat hypercalcaemia, reduce pain and decrease the risk of fracture by affecting bone-metabolism and inhibiting osteoclastic activity, particularly in patients with myeloma, breast and prostate cancer.⁷

Radiotherapy and spinal stereotactic radiosurgery. Indications for radiotherapy in MESCC include highly radiosensitive tumours, such as lymphoma, myeloma and small-cell carcinoma of the lung, without neurological impairment, spinal instability or mechanical pain and no significant bony compromise of the spinal canal, and patients whose life expectancy is less than three months.^{7,20} Conventional radiotherapy is typically administered in eight to ten fractions with a total dose of 25 Gy to 40 Gy.²⁰ Generous margins are required within the radiation field to compensate for patient movements. Therefore, adjacent tissues, including the spinal cord, receive radiation. Fractionisation allows the normal tissues to tolerate the radiation exposure optimally. The addition of a procedure to stabilise the spine when radiotherapy has been administered is thought to be critical for managing axial pain and providing neurological recovery. Radiotherapy should be administered after the operation when the wound has healed because of the risk of post-operative complications, especially wound infection and dehiscence.²⁵

Spinal stereotactic radiosurgery (SRS) is an emerging form of radiotherapy which may have advantages in the treatment of MESCC. Spinal SRS and intensity-modulated radiotherapy, another form of radiotherapy, allow radiation to be delivered more accurately while minimising the exposure to normal tissues. The former can be administered in one or two sessions on an outpatient basis. Stereotactic localisation achieves accurate targeting for multiple radiation beams to converge on the lesion of interest at a high dose, while limiting the exposure of adjacent normal tissues. The total dose delivered ranges from 8 Gy to 18 Gy. Current commercial spinal SRS systems include Novalis (BrainLAB, Heinstetten, Germany) and CyberKnife (Accuray Incorporated, Sunnyvale, California). A recent clinical study using the CyberKnife to treat 58 spinal metastatic lesions showed a significant improvement in pain, which was still present one year later.²⁶ Of the patients who presented with a neurological deficit, 31% improved, 47% were unchanged and 22% were worse. The quality of life was maintained, with the treatment producing only mild side-effects. Metastatic lesions which had not undergone previous irradiation had a rate of control of the tumour of 100%.

A recent systematic review of the literature has shown that radiosurgery is safe and provides incremental benefit over conventional radiotherapy, with a more durable symptomatic response and local control independent of the histology, even when fractionated radiotherapy has been given previously.²⁷ However, it does not address spinal instability and gives highly focal radiation with a limited ability to deliver radiation to large lesions.²⁰

Operative management

The indications for surgery include the need to establish a diagnosis, spinal instability, epidural compression with cord dysfunction from bone or tumour, radioresistant tumours, those which recur despite radiotherapy and neurological deterioration during the latter. The timing of surgery is an important factor in contributing to the likely neurological outcome. If definitive treatment of MESCC is planned, this should be started within 24 hours.⁷ If there is rapid deterioration in the neurological state, the operation must be undertaken as soon as possible. If deterioration is gradual surgery can be planned for the next scheduled list.

Early studies comparing the efficacy of decompressive laminectomy without stabilisation to that of radiotherapy found no difference in the outcome or survival.²⁸ This surgical approach did not address the most common site for spinal metastases, namely in the vertebral body which causes neural compression as the tumour extends dorsally and destabilises the spine.²⁰ Subsequently, surgery was usually not advocated until radiotherapy had failed. Technical advances which allow circumferential decompression of the spinal cord combined with stabilisation of the spine have allowed more aggressive and more effective surgical procedures to be used for patients with MESCC.

Witham et al²⁰ observed in their review in 2006 that a mean of 36% of patients improved with radiotherapy

alone, while 17% became worse. This result is similar to that obtained in the series of trials of laminectomy with or without radiotherapy, which resulted in improved neurological function in a mean of 42% of patients and worse function in 13%.²⁰ If posterior decompression was performed in conjunction with stabilisation the functional outcome was better with a mean motor improvement in 64% of patients.²⁰ In these series, relief from pain was achieved in a high percentage of patients with a mean mortality rate comparable with that of laminectomy alone (5% *vs* 6%).

Functional neurological improvement was even more dramatic in patients undergoing circumferential decompression and stabilisation with a mean neurological improvement of 75% and a mean mortality rate of 10%.²⁰ A recent randomised, prospective clinical trial of direct decompressive surgical resection and stabilisation with radiotherapy (n = 50) *vs* radiotherapy alone (n = 51) for MESCC, revealed a statistically significant difference in the ability to walk in patients treated by operation compared with those treated by radiotherapy alone (84% *vs* 57%, p = 0.001).²⁹ Patients in the surgery group retained the ability to walk for significantly longer than those in the latter group with a median of 122 days as opposed to 13 days (p = 0.003). Of those able to walk before treatment, 94% (32 of 34) in the surgery group were still able to do so compared with 74% (26 of 35) in the radiotherapy group (median 153 days *vs* 54 days, p = 0.024). Of the patients in the surgery group who could not walk before treatment, 62% (10 of 16) regained the ability to do so, compared with only 19% (3 of 16) in the radiotherapy group (p = 0.012). Significant differences in the maintenance of continence, muscle strength (American Spinal Injury Association (ASIA) score³⁰), functional ability (Frankel score³¹) and increase in survival time were also observed in the surgery group relative to the radiotherapy group. The median survival in the surgery group was 126 days compared with 100 days in the latter group (p = 0.033). The 30-day morbidity rates were higher in the radiotherapy group, whereas the 30-day mortality rates were not statistically different. The conclusion from this study was that selected patients with MESCC treated by surgery and radiotherapy maintained the ability to walk for longer, and recovered the ability to walk more frequently, than those treated by radiotherapy alone. Continence and the ability to walk appeared to persist for the lifetime of the patient in those treated by surgery and radiotherapy. Surgical treatment also resulted in a modest improvement in survival time.²⁹

Improved results using better surgical techniques of circumferential decompression and stabilisation³²⁻³⁴ have led to the concept that, in some circumstances, the outcome may be improved after total spondylectomy or *en bloc* resection. It has been suggested that this may be a potential cure for patients with involvement at a single spinal level without metastases, in certain tumours such as renal-cell carcinoma.³⁵⁻⁴⁰ However, a recent review recommends that

for such patients stereotactic radiosurgery should be the first line of treatment rather than *en bloc* excision.⁴¹

The definition of metastatic or neoplastic instability is still not clear. Fracture-dislocation, a translational deformity, and significant collapse with mechanical pain are accepted criteria for surgical stabilisation. Three-column destruction, progressive deformity and pain may also be considered for stabilisation procedures. Fourney and Gokaslan⁴² have proposed the Spinal Instability Neoplastic Score, which encompasses the location of the tumour, the character and type of pain related to movement, the quality of the bone, spinal alignment, vertebral collapse and involvement of the posterior elements. This may prove to be valuable in deciphering which patients require a stabilisation procedure.⁴³ Patients who are paraplegic or tetraplegic from MESCC may also benefit from stabilisation to relieve pain (Fig. 1).⁷

Surgical techniques. The surgical approach is dictated by the location of the tumour, the site of compression on the spinal cord, the histology of the tumour and the type of spinal reconstruction or stabilisation which will be required once the tumour has been resected. Vascular tumours, including renal-cell carcinoma, thyroid carcinoma and hepatocellular carcinoma, must be embolised pre-operatively to decrease blood loss during surgery. Intra-operative neurophysiological monitoring using somatosensory and motor-evoked potentials are useful adjuncts.

Anterior approaches commonly provide the best access to metastatic tumours causing compression of the cord since these frequently arise from the vertebral body and extend dorsally. The upper thoracic (T1-4) region presents a particular challenge and may require the combination of an anterolateral cervical approach and a sternotomy, with or without thoracotomy.⁴⁴ However, a posterior transpedicular approach to decompress the ventral aspect of the spinal cord is becoming more popular because of the invasive nature of the anterior approach, particularly at these levels (Fig. 2).^{45,46} The T5-10 levels are best approached through a thoracotomy from the right side to avoid the great vessels and aortic arch. However, the bulk of the extravertebral tumour usually dictates the side of approach.⁴⁴ Approaches to the T11-L1 region often require a combined thoracotomy and a retroperitoneal approach, and metastases at L2-4 can be reached through an incision in the flank. Tumour limited to L5 is most commonly managed by posterior decompression and stabilisation.²⁰ The Spinal Oncology Study Group has advocated the use of these approaches for the lower thoracic and lumbar spine, with the final choice depending on the clinical presentation and the preference of the surgeon and the patient.⁴⁷

Stabilisation of the spine is an integral part of the operation since the anterior and posterior approaches to achieving circumferential decompression are significantly destabilising. Stabilisation of the anterior column can be achieved by the use of allograft, or autograft, titanium cages cut to size, plates or polymethylmethacrylate

Fig. 2a

Fig. 2b

Fig. 2c

Figure 2a – MR scans (T1-weighted sagittal and axial) of a 67-year-old man with a history of rectal carcinoma who presented with increasing upper back pain, showing lytic lesions at the T3 and T4 levels involving the vertebral bodies, as well as epidural and left pedicle infiltration. A needle biopsy confirmed metastases from rectal carcinoma. Radiotherapy was given, but there was neurological deterioration. Figure 2b – Intra-operative photograph shows a costotransversectomy, transpedicular decompression, vertebrectomies of T3 and T4 and stabilisation. Figure 2c – Anteroposterior and lateral radiographs showing the reconstruction of the anterior column by allograft and the posterior column by transpedicular screws and bilateral rods.

(PMMA) secured by Steinmann pins,⁴⁶ or even by a chest tube.⁴⁸ A range of trabecular metal implants and expandable titanium cages is also available. Combined anteroposterior decompression and stabilisation can be carried out either in a single setting or staged. Posterior stabilisation with pedicle-screw instrumentation is advocated in patients with significant kyphosis, with lesions at the thoracolumbar junction or to supplement anterior reconstruction in patients who undergo two or more adjacent vertebrectomies.²⁰

Minimally invasive options. A variety of percutaneous procedures is available for improving pain and achieving stabilisation, including vertebroplasty, kyphoplasty with or without radiofrequency ablation and percutaneous pedicle screw placement (the insertion of a pedicle screw through minimally invasive techniques.) Video-assisted thoracoscopic surgery can be used to access the spine from T1-T12⁴⁹ and perform corpectomies for resection of the tumour.⁵⁰

Thoracoscopy has a steep learning curve and requires the surgeon to have a good knowledge of segmental surgical anatomy as well as the technical skill to use the long working arm of the equipment.⁵⁰ Laparoscopic approaches can also be used for retroperitoneal access to the lumbar spine for decompression and corpectomy.⁵¹ With the advent of computer-assisted surgery, surgeons are better able to place percutaneous pedicle screws.⁵²

Percutaneous vertebroplasty and kyphoplasty. Percutaneous injection of PMMA into a vertebral body which has collapsed due to metastatic tumour has been effective for the treatment of pain. Vertebroplasty involves the direct injection of PMMA into the vertebral body, whereas with kyphoplasty an expandable balloon is first placed to attempt to reduce the kyphosis and to create a cavity for the subsequent injection of PMMA. Epidural compression of the spinal cord is a relative contraindication to vertebro-

plasty or kyphoplasty. However, in patients who are poor surgical candidates, vertebroplasty or kyphoplasty in combination with radiotherapy can result in dramatic relief from pain. Complications are rare and are usually related to leakage of PMMA beyond the confines of the vertebral body. In a recent series of 97 procedures in patients with intractable pain secondary to pathological fractures of the vertebral body marked or complete relief from pain was achieved in 84%.⁵³ There were no deaths or complications related to the procedure. Precise indications are evolving for vertebroplasty and kyphoplasty in relation to metastatic spinal disease. The technique is safe and effective for treating intractable pain secondary to vertebral fractures and may be especially effective in conjunction with radiotherapy for patients with radiosensitive tumours such as multiple myeloma.⁵⁴ However, it must be emphasised that this is not a treatment for epidural compression of the cord, but provides a less invasive means of stabilisation of the spine and can be useful in providing support of the anterior column when used in combination with posterior decompression and pedicle-screw fixation.

Radiofrequency ablation and cryotherapy. Plasma-mediated radiofrequency, which lacks the collateral heating associated with conventional radiofrequency, has been used to ablate tissues such as intervertebral discs and cartilage, and to debulk a tumour mass before vertebroplasty or kyphoplasty. The technique involves the percutaneous insertion of a cannula through which a plasma-mediated radiofrequency wand is passed. The tumour tissue can be ablated, vaporising the mass into nitrogen and carbon dioxide. The wand has a coagulation mode for use in hypervascular tumours. When most of the tumour has been ablated, the cavity can be filled with cement. The initial results in 28 patients showed no complications and significant reduction in the pain scores.⁵⁵

Cryoablation has been used in the management of pain, rehabilitation and for posterior spinal pain syndromes arising from the facet joint or the region of the sinuvertebral nerve.^{56,57} The successful use of cryosurgery to ablate lesions in the vertebral body has also been described.⁵⁸

Aftercare and rehabilitation

All patients who are on bed rest are given thigh-length graduated compression stockings and/or intermittent pneumatic compression or foot impulse devices. Subcutaneous low-molecular-weight heparin is given to all patients with MESCC, especially if paraplegic, since the risk of thromboembolic complications is high. After operation mobilisation is encouraged as the pain improves, but if patients are on bed rest risk assessments for pressure ulcers are performed and log rolling carried out every two to three hours. Changes in bowel and bladder function are assessed at the initial presentation and then daily, following a recommended management programme for incontinence.⁷

The field of spinal oncology is evolving at a fast pace and as the survival rates from cancer improve metastatic spinal

pain and cord compression will become more prevalent. The surgical techniques for decompression and stabilisation of the spine have advanced, leading to an improved outcome. Patients with MESCC treated by combined decompression and stabilisation and radiotherapy can remain mobile longer, and those who cannot walk when first seen have a better chance of regaining mobility. As techniques evolve further, patients will have more access to less invasive options such as the percutaneous methods of stabilisation described. The concentration of such care in specialist centres is important in order to maintain the best outcome, manage the complications as they arise and to continue prospective audit.

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References

1. Aaron AD. The management of cancer metastatic to bone. *JAMA* 1994;272:1206-9.
2. Cobb CA 3rd, Leavens ME, Eckles N. Indications for nonoperative treatment of spinal cord compression due to breast cancer. *J Neurosurg* 1977;47:653-8.
3. Wong DA, Fornasier VL, MacNab I. Spinal metastases: the obvious, the occult, and the impostors. *Spine* 1990;15:1-4.
4. Loblaw DA, Laperriere NJ, Mackillop WJ. A population-based study of malignant spinal cord compression in Ontario. *Clin Oncol (R Coll Radiol)* 2003;15:211-17.
5. Barron KD, Hirano A, Araki S, Terry RD. Experiences with metastatic neoplasms involving the spinal cord. *Neurology* 1959;9:91-106.
6. Schaberg J, Gainor BJ. A profile of metastatic carcinoma of the spine. *Spine* 1985;10:19-20.
7. No authors listed. Metastatic spinal cord compression: diagnosis and management of patients at risk of and with metastatic spinal cord compression. NICE guidelines CG75, November 2008. <http://www.nice.org.uk/nicemedia/pdf/CG75NICEguideline.pdf> (date last accessed 15 April 2010).
8. Livingstone KE, Perrin RG. The neurosurgical management of spinal metastases causing cord and cauda equina compression. *J Neurosurg* 1978;49:839-43.
9. Helweg-Larsen S, Sørensen PS. Symptoms and signs in metastatic spinal cord compression: a study from first symptom until diagnosis in 153 patients. *Eur J Cancer* 1994;30:396-8.
10. Sciubba DM, Gokaslan ZL. Diagnosis and management of metastatic spine disease. *Surg Oncol* 2006;15:141-51.
11. Schiff D. Spinal cord compression. *Neurol Clin* 2003;21:67-86.
12. Arguella F, Baggs RB, Duerst RE, et al. Pathogenesis of vertebral metastasis and epidural spinal cord compression. *Cancer* 1990;65:98-106.
13. Levack P, Graham J, Collie D, et al; Scottish Cord Compression Group. Don't wait for a sensory level – listen to the symptoms: a prospective audit of the delays in diagnosis of malignant cord compression. *Clin Oncol (R Coll Radiol)* 2002;14:472-80.
14. Yuh WT, Zachar CK, Barloon TJ, et al. Vertebral compression fractures: distinction between benign and malignant causes with MR imaging. *Radiology* 1989;172:215-18.
15. Baur A, Stähler A, Arbogast S, et al. Acute osteoporotic and neoplastic vertebral compression fractures: fluid sign at MR imaging. *Radiology* 2002;225:730-5.
16. Jung HS, Jee WH, McCauley TR, Ha KY, Choi KH. Discrimination of metastatic from acute osteoporotic compression fractures with MR imaging. *Radiographics* 2003;23:179-87.
17. Tomita K, Kawahara N, Kobayashi T, et al. Surgical strategy for spinal metastases. *Spine* 2001;26:298-306.
18. Tokuhashi Y, Matsuzaki H, Oda H, Oshima M, Ryu J. A revised scoring system for preoperative evaluation of metastatic spine tumor prognosis. *Spine* 2005;30:2186-91.
19. Yu MK, Buys SS. Medical management of skeletal metastasis. *Neurosurg Clin N Am* 2004;15:529-36.
20. Witham TF, Khavkin YA, Gallia GL, Wolinsky JP, Gokaslan ZL. Surgery insight: current management of epidural spinal cord compression from metastatic spine disease. *Nat Clin Pract Neurol* 2006;2:87-94.

21. Delattre JY, Arbit E, Rosenblum MK, et al. High dose versus low dose dexamethasone in experimental epidural spinal cord compression. *Neurosurgery* 1988;22:1005-7.
22. Delattre JY, Arbit E, Thaler HT, Rosenblum MK, Posner JB. A dose-response study of dexamethasone in a model of spinal cord compression caused by epidural tumor. *J Neurosurg* 1989;70:920-5.
23. Turner S, Maroszek B, Timms I, Boyages J. Malignant spinal cord compression: a prospective evaluation. *Int J Radiat Oncol Biol Phys* 1993;26:141-6.
24. Vecht CJ, Haaxma-Reiche H, van Putten WL, et al. Initial bolus of conventional versus high-dose dexamethasone in metastatic spinal cord compression. *Neurology* 1989;39:1255-7.
25. Klimo P Jr, Schmidt MH. Surgical management of spinal metastases. *Oncologist* 2004;9:188-96.
26. Degen JW, Gagnon GJ, Voyadzis JM. CyberKnife stereotactic radiosurgical treatment of spinal tumors for pain control and quality of life. *J Neurosurg Spine* 2005;2:540-9.
27. Gerszten PC, Mendel E, Yamada Y. Radiotherapy and radiosurgery for metastatic spine disease: what are the options, indications, and outcomes? *Spine* 2009;34(Suppl):78-92.
28. Young RF, Post EM, King GA. Treatment of spinal epidural metastases: randomised prospective comparison of laminectomy and radiotherapy. *J Neurosurg* 1980;53:741-8.
29. 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* 2005;366:643-8.
30. No authors listed. *International standards for the neurological classification of spinal cord*. Chicago: American Spinal Injury Association, 1996.
31. Frankle HL. Ascending cord lesion in the early stages following spinal injury. *Paraplegia* 1969;7:111-16.
32. Fourny DR, Gokaslan ZL. Anterior approaches for thoracolumbar metastatic spine tumours. *Neurosurg Clin N Am* 2004;15:443-51.
33. Fourny DR, Abi-Said D, Rhines LD, et al. Simultaneous anterior-posterior approach to the thoracic and lumbar spine for the radical resection of tumors followed by reconstruction and stabilisation. *J Neurosurg* 2001;94(Suppl):232-43.
34. Manabe S, Tateishi A, Abe M, Ohno T. Surgical treatment of metastatic tumors of the spine. *Spine* 1989;14:41-7.
35. Sakaura H, Hosono N, Mukai Y, et al. Outcome of total en bloc spondylectomy for solitary metastasis of the thoracolumbar spine. *J Spinal Disord Tech* 2004;17:297-300.
36. Tomita K, Kawahara N, Baba H, et al. Total spondylectomy for solitary spinal metastases. *Int Orthop* 1994;18:291-8.
37. Tomita K, Toribatake Y, Kawahara N, Ohnari H, Kose H. Total en bloc spondylectomy and circumspinal decompression for solitary spinal metastasis. *Paraplegia* 1994;32:36-46.
38. Boriani S, Biagini R, De Iure F, et al. En bloc resections of bone tumors of the thoracolumbar spine: a preliminary report on 29 patients. *Spine* 1996;21:1927-31.
39. Sundaresan N, Rothman A, Manhart K, Kelliher K. Surgery for solitary metastases of the spine: rationale and results of treatment. *Spine* 2002;27:1802-6.
40. Sakaura H, Hosono N, Mukai Y, et al. Outcome of total en bloc spondylectomy for solitary metastasis of the thoracolumbar spine. *J Spinal Disord Tech* 2004;17:297-300.
41. Bilsky MH, Laufer I, Burch S. Shifting paradigms in the treatment of metastatic spine disease. *Spine* 2009;34(Suppl):101-7.
42. Fourny DR, Gokaslan ZL. Spinal instability and deformity due to neoplastic conditions. *Neurosurg Focus* 2003;14:e8.
43. Sundaresan N, Boriani S, Okuno S. State of the art management in spine oncology: a worldwide perspective on its evolution, current state, and future. *Spine* 2009;34(Suppl):7-20.
44. Fourny DR, Gokaslan ZL. Thoracolumbar spine: surgical treatment of metastatic disease. *Curr Opin Orthop* 2003;14:144-52.
45. Wang JC, Boland P, Mitra N, et al. Single-stage posterolateral transpedicular approach for resection of epidural metastatic spine tumors involving the vertebral body with circumferential reconstruction: results in 140 patients. *J Neurosurg Spine* 2004;1:287-98.
46. Akeyson EW, McCutcheon IE. Single-stage posterior vertebrectomy and replacement combined with posterior instrumentation for spinal metastasis. *J Neurosurg* 1996;85:211-20.
47. Polly DW Jr, Chou D, Sembrano JN, Ledonio CG, Tomita K. An analysis of decision making and treatment in thoracolumbar metastases. *Spine* 2009;34(Suppl):118-27.
48. Fourny DR, Abi-Said S, Lang FF, McCutcheon IE, Gokaslan ZL. The use of pedicle screw fixation in the management of malignant spinal disease: experience in 100 consecutive procedures. *J Neurosurg* 2001;94(Suppl):25-37.
49. Kim DH, Jaikumar S, Kam AC. Minimally invasive spine instrumentation. *Neurosurgery* 2002;51(Suppl):15-25.
50. Han PP, Kenny K, Dickman CA. Thoracoscopic approaches to the thoracic spine: experience with 241 surgical procedures. *Neurosurgery* 2002;51(Suppl):88-95.
51. Mühlbauer M, Pfisterer W, Eyb R, Knosp E. Minimally invasive retroperitoneal approach for lumbar corpectomy and anterior reconstruction: technical note. *J Neurosurg* 2000;93(Suppl):161-7.
52. Holly LT, Foley KT. Three-dimensional fluoroscopy-guided percutaneous thoracolumbar pedicle screw placement: technical note. *J Neurosurg* 2003;99(Suppl):324-9.
53. Fourny DR, Schomer DF, Nader R, et al. Percutaneous vertebroplasty and kyphoplasty for painful vertebral body fractures in cancer patients. *J Neurosurg* 2003;98(Suppl):21-30.
54. Mendel E, Bourekas E, Gerszten P, Golan JD. Percutaneous techniques in the treatment of spine tumours: what are the diagnostic and therapeutic indications and outcomes? *Spine* 2009;34(Suppl):93-100.
55. Georgy BA, Wong W. Plasma-mediated radiofrequency ablation assisted percutaneous cement injection for treating advanced malignant vertebral compression fractures. *AJNR Am J Neuroradiol* 2007;28:700-5.
56. Gleizes V, Viguier E, Féron JM, Canivet S, Lavaste F. Effects of freezing on the biomechanics of the intervertebral disc. *Surg Radiol Anat* 1998;20:403-7.
57. Skliarenko ET, Tarabanova LV, Pashkov EP. Cryotherapy of pain syndromes associated with degenerative-dystrophic diseases of the spine. *Ortop Travmatol Protez* 1986;10:28-31 (in Russian).
58. Kollender Y, Meller I, Bickels J, et al. Role of adjuvant cryosurgery in intralesional treatment of sacral tumors. *Cancer* 2003;97:2830-8.