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ORIGINAL ARTICLE

# Spinal tumours: recommendations of the Polish Society of Spine Surgery, the Polish Society of Oncology, the Polish Society of Neurosurgeons, the Polish Society of Oncologic Surgery, the Polish Society of Oncologic Radiotherapy, and the Polish Society of Orthopaedics and Traumatology

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## Abstract

**Purpose** The purpose of these recommendations is to spread the available evidence for evaluating and managing spinal tumours among clinicians who encounter such entities.

**Methods** The recommendations were developed by members of the Development Recommendations Group representing seven stakeholder scientific societies and organizations of specialists involved in various forms of care for patients with spinal tumours in Poland. The recommendations are based on data yielded from systematic reviews of the literature identified through electronic database searches. The strength of the recommendations was graded according to the North American Spine Society's grades of recommendation for summaries or reviews of studies.

**Results** The recommendation group developed 89 level A-C recommendations and a supplementary list of institutions able to manage primary malignant spinal tumours, namely, spinal sarcomas, at the expert level. This list, further called an appendix, helps clinicians who encounter spinal tumours refer patients with suspected spinal sarcoma or chordoma for pathological diagnosis, surgery and radiosurgery. The list constitutes a basis of the network of expertise for the management of primary malignant spinal tumours and should be understood as a communication network of specialists involved in the care of primary spinal malignancies.

**Conclusion** The developed recommendations together with the national network of expertise should optimize the management of patients with spinal tumours, especially rare malignancies, and optimize their referral and allocation within the Polish national health service system.

**Keywords** Primary malignant spinal tumours · Spinal metastases · Sarcoma · Multidisciplinary management of spinal tumours · Benign primary spinal tumours

## Introduction

Initially, the only purpose of our project was to develop recommendations for the evaluation and management of spinal tumours among clinicians caring for such entities. To the best of our knowledge, no comprehensive recommendations regarding the full spectrum of spinal tumours have been published thus far. Soon after starting the project, we added another goal: the development of a network of expertise at a national level for the management of primary malignant spinal tumours in Poland with a plan to incorporate this network into the existing organizational structure of the Polish national cancer care system. Such a network will follow recommendations of the European Union Joint Action on Cancer and the European Partnership for Action Against Cancer (EPAAC) [1].

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The EPAAC recommends the establishment of networks of expertise in the management of soft tissue and bone sarcomas in regions where it is not possible to establish comprehensive centres for their management. In Poland, similar to the majority of other countries, such centres offering comprehensive expertise under the one roof do not exist or are very rare. Our expertise network seems to be a reasonable alternative given the lack of such centres and a good response to the EPAAC recommendations.

We believe that with the national expertise network, our recommendations have an increased chance to be fully met in everyday clinical practice.

Incorporation of our expertise network into the existing national system of cancer care in Poland should be straightforward. This is because in Poland, interdisciplinarity in the management of cancer is a fundamental principle and a statutory requirement of a Polish national cancer care system. This principle is executed with relative ease for most oncology patients in Poland, but clinicians and patients can experience problems in regard to very rare malignancies, such as spinal sarcomas and chordomas. Access to the expertise network for both patients and clinicians encountering spinal tumours should complement the Polish cancer care system in the management of rare primary spinal malignancies. Currently, specialists with expertise in these tumours are dispersed across the country and, consequently, problems with coordinated referral and interdisciplinary management of these patients exist. In practice, interdisciplinary services for the management of rare spinal tumours are not available under the one roof, even at quaternary or university hospitals. Furthermore, the interdisciplinary management of these tumours may not be available, even within a single broader region of the country. Complex oncologic spine surgery can be performed by a specialist in one corner of the country, molecular histology of sarcomas in another corner, and proton beam therapy or radiosurgery in yet another corner. Similar dispersions of expertise and facilities for the management of rare malignancies can be found worldwide, including in highly developed countries. We believe that a dedicated expertise network for rare spinal tumours at the national level will improve the coordinated interdisciplinary management of patients, despite the dispersion of experts and facilities across the country.

## Methods

### The recommendations development group

The project to develop such recommendations was an initiative of the Executive Committee of the Polish Society of Spine Surgery. The Committee invited some stakeholder organizations to the project to ensure broad representation of all specialties involved in the care of patients with spinal tumours. Ultimately, seven organizations, including the Polish Society of Spine Surgery, agreed to participate in the project: the Polish Society of Oncology, the Polish Society of Neurosurgeons, the Polish Society of Oncologic Surgery, the Polish Society of Oncologic Radiotherapy, the Polish Society of Orthopaedics and Traumatology, and the Department of Soft Tissue/Bone Sarcoma and Melanoma at the Maria Sklodowska-Curie National Research Institute of Oncology, Warsaw, Poland. Each one nominated representatives to serve on the Recommendation Development Group. In total, 20 volunteers participated in this effort, including the following specialists: (1) neurosurgeons and orthopaedic surgeons with expertise in the field of spine surgery, (2) radiation oncologists, (3) medical oncologists, and (4) experts in the field of sarcoma from the Department of Soft Tissue, Bone Sarcoma and Melanoma at the Maria Sklodowska-Curie Institute Oncology Center in Poland.

### Grading recommendations and level of evidence

The recommendations were based on systematic reviews of the literature identified from searching electronic databases. The strength of the recommendations was graded according to the North American Spine Society's Grades of Recommendation for Summaries or Reviews of Studies (Tables 1 and 2). A: good evidence (level I studies with consistent findings) for or against recommending intervention; B: fair evidence (level II or III studies with consistent findings) for or against recommending intervention; C: poor quality evidence (level IV or V studies) for or against recommending intervention; and I: insufficient or conflicting evidence not allowing for a recommendation for or against intervention [2, 3].

Each identified source of evidence was rated in terms of the strength of yielded evidence with the use of levels of evidence for primary research questions as adopted by the North American Spine Society in January 2005 and other societies and journals, namely, the American Academy of Orthopaedic Surgeons, Pediatric Orthopaedic Society of North America, Clinical, Orthopaedics and Related Research, Journal of Bone and Joint Surgery and Spine (Table 2) [3].

**Table 1** The strength of recommendations was graded according to the North American Spine Society's grades of recommendation for summaries or reviews of studies

| |
|---|
| *A* good evidence (level I studies with consistent finding) |
| *B* fair evidence (level II or III studies with consistent findings) |
| *C* poor quality evidence (level IV or V studies) |
| *I* insufficient or conflicting evidence not allowing a recommendation for or against intervention |

**Table 2** Levels of evidence for primary research questions as adopted by the North American Spine Society January 2005 and other societies and journals, namely the American Academy of Orthopaedic Surgeons, Pediatric Orthopaedic Society of North America, clinical, orthopaedics and related research, Journal of Bone and Joint Surgery and Spine

| |
|---|
| *Level I* high-quality randomized controlled trial (RCT) with statistically significant differences or no statistically significant differences but narrow confidence intervals, systematic review of level I RCTs (with homogenous study results) |
| *Level II* lower-quality RCT (e.g., < 80% follow-up, no blinding, or improper randomization), prospective comparative study, systematic review of level II studies or level 1 studies with inconsistent results |
| *Level III* case control study, retrospective comparative study, systematic review of level III studies |
| *Level IV* case series |
| *Level V* expert opinion |

## Organization of the literature search

Members of the Recommendation Development Group were divided into several working teams, each performing a database search for one or more topics allocated to them in accordance with the specialties of the team members. There were 11 core topics: epidemiology of spinal tumours, aetiology and classification of spinal tumours, imaging diagnostics of spinal tumours, clinical diagnosis and grading scales, biopsy and management of biopsy samples, histological diagnosis, chemotherapy and radiotherapy of primary tumours in particular, chemotherapy and radiotherapy of metastatic tumours, surgical treatment of primary malignant spinal tumours, surgical treatment of benign spinal tumours, and surgical treatment of metastatic tumours. Most malignant primary tumours, namely, osteosarcoma, chondrosarcoma, Ewing sarcoma, chordoma, osteoblastoma, and solitary plasmocytoma, and many benign tumours, aneurysmal cysts and giant cell tumours in particular, were searched for separately and reviewed by working teams according to the specialties of the team members. Each team had the freedom to identify papers relevant to the allocated topic. It was a duty of each team to critically assess the quality of the identified studies and downgrade their levels of evidence if any shortcomings were present in the execution of the reviewed study.

## Formulation of recommendations

All members of the Recommendation Development Group participated in the recommendation development process. Each team proposed preliminary recommendations in a structured way that included formulating the recommendation and the following: (1) classifying the strength of the formulated recommendation, (2) classifying the quality of the study that the recommendation was based on, (3) referencing the source of the study, and (4) stating the type of the study, e.g., randomized controlled trial, retrospective study, and expert opinion. The preliminary recommendations were summarized in a table by each working team (Table 3). Tables with preliminary recommendations from all working teams were compiled into one table embedded in a Word file that was available online for all members of the Recommendation Development Group. The teams were asked to review the table and provide written remarks, comments, objections or opinions in the comments panel of the Word file based on their areas of expertise. This process was supervised by four chairs who were members of the development group but were not involved in the literature search and instead chaired all the meetings and voting sessions of the group. Once the preliminary recommendations were reviewed, each single recommendation was separately subjected to voting during a series of meetings of the whole Recommendation Development Group. Every single preliminary recommendation was separately accepted as a final recommendation when at least 75% of members voted positively. Recommendations that did not achieve this result during the first round of voting were returned to the appropriate working team for revision. Based on the revision, the recommendation could be either rejected or reformulated by the working team and subjected to the second review and vote by the whole Development Group during the subsequent meetings. Those preliminary recommendations that were not accepted during a second vote were ultimately rejected or when representing a crucial issue, put on a discrepancy list.

## Expertise network for multidisciplinary management of rare primary spinal tumours

Based on internal surveys in the stakeholder societies represented in the development group, we created a list of institutions, hospitals, teams and individual colleagues with expertise in the diagnosis and treatment of rare malignant spinal tumours. Specifically, we inquired about facilities offering in-depth molecular histological diagnostics, stereotactic body radiation therapy of the spine, proton beam therapy, and complex oncologic spine surgery. Each scientific society was asked to provide such a list with regard to its specialties. A survey among the members of the Polish Society of Spine Surgery concerning their experience in complex oncologic spine surgery, namely, en bloc Enneking-appropriate resections, allowed us to create a list of centres and individual

**Table 3** Template of the table which was filled in with preliminary recommendations by each working team

| Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|
| Formulated recommendation | To be chosen from four possible options<br>A, B, C, I<br>(see Table 1) | Reference to the source of evidence (journal articles, textbooks, etc.) | To be chosen from five possible options<br>I–V<br>(see Table 2) | To be chosen from the following: RCT, systematic reviews, prospective studies, retrospective studies, case series, expert opinions |

colleagues who have expertise in this type of surgery. These experts were also asked about their willingness and readiness to accept patients requiring this type of surgery from other institutions/colleagues on a regular basis.

## Results

Eighty-nine recommendations were developed and accepted by the Recommendation Development Group and divided into four sections: (1) diagnostics, (2) primary tumours, (3) metastatic tumours, and (4) discrepancies (Tables 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27 respectively). The list of recommendations will be available on the homepages of stakeholder organizations participating in the development of recommendations and accompanied by an appendix including a list of institutions, teams and individual specialists with expertise in the diagnostics and management of rare primary malignant tumours to optimize patient referral and allocation within the cancer care system of Poland (Table 28).

## Discussion

As mentioned above, interdisciplinarity in the management of cancer is a fundamental principle and a statutory requirement of the Polish national cancer care system.

While the principle of interdisciplinarity in the management of most spinal tumours is relatively easy to execute, this is not the case for primary malignant spinal tumours requiring sophisticated molecular diagnostics as well as complex oncologic spine surgery.

No single centre in Poland provides complete management of rare primary malignant spinal tumours from in-depth molecular histological diagnosis through complex oncologic spine surgery to spine radiosurgery and chemotherapy in one institution.

Currently, patients with such tumours and some clinicians involved in the care of such patients may not be aware of the centres offering unique molecular diagnosis or top-level oncologic surgical treatment of the spine. With the dispersion of these highly specialized services across Poland, it may take time and effort to find an institution with the required facilities. A patient may undergo surgical treatment in one place and radiotherapy or chemotherapy in another, while having molecular diagnosis done in yet another place. In everyday practice, such patients and clinicians may both feel lost in regard to deciding which referral centre can offer the most appropriate diagnostics and treatment. Based on internal surveys within scientific societies represented in the development group, we prepared a list of institutions and colleagues with expertise

**Table 4** Recommendations. Imaging diagnostics. General rules

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | MRI a method of choice in the detection of neoplastic invasion in the spine<br>The sensitivity of multislice computed tomography is significantly lower in detecting metastases to the spine than that of MRI. For this reason, MRI is the method of choice as the most sensitive tool in the detection of neoplastic invasion in the spine | B | [4] | III | Retrospective |
| 2 | MRI and CT to identify patients at high risk for vertebral fracture and spinal cord compression (SCC)<br>The current clinical consensus favours MRI and CT for the investigation of SCC and vertebral fracture | B | [5] | III | Systematic review of literature |
| 3 | MRI as a more sensitive imaging technique than skeletal scintigraphy in detecting spinal metastases | B | [6] | II | Prospective |
| 4 | Sagittal T1-weighted and/or T2-weighted axial projections as necessary to detect vertebral metastases, epidural tumour masses and the degree of compression of the spinal cord | B/C | [7] | II/III | Randomized prospective study |
| 5 | Imaging diagnostics of the spine in patients with prostate cancer even in the absence of neurological deficits<br>A significant proportion of patients with metastasis may harbour overt or occult spinal cord compression in the absence of functional neurologic deficits | B/C | [8, 9] | II/III | Prospective and retrospective study |
| 6 | T2-weighted images for grading spinal canal compromise with the Epidural Spinal Cord Compression scale (ESCC)<br>T2-weighted images are superior indicators of epidural spinal cord compression to T1-weighted images with and without gadolinium<br>The ESCC scale provides a valid and reliable instrument that may be used to describe the degree of ESCC based on T2-weighted MR images | C | [10] | V | Validation study |
| 7 | Spinal instability neoplastic score (SINS) for the assessment of spinal instability due to neoplastic disease<br>SINS demonstrates near-perfect inter- and intraobserver reliability in determining three clinically relevant categories of stability. The sensitivity and specificity of SINS for potentially unstable or unstable lesions are high | C | [11] | III | Validation study |
| 8 | Radiology reports should include the spinal instability neoplastic score (SINS) in patients with neoplastic disease of the spine<br>Among radiation oncologists, SINS is a highly reliable, reproducible, and valid assessment tool to address a key question in tumour-related spinal disease: is the spine 'stable' or is there a 'current or possible instability' that warrants surgical assessment? | I | [12] | V | Multicentre validation study |

in the diagnosis and treatment of rare malignant spinal tumours, namely sarcomas and chordomas. The list will be available as an appendix to the recommendations on the homepages of the stakeholder organizations. The list aims to give clinicians involved in the care of patients with spinal tumours clues on where to refer patients with rare spinal malignancies for optimal management, especially in regard to complex oncologic spine surgery. The colleagues experienced in this type of surgery declared they would be ready to accept such cases on a regular basis. The appendix will also include a list of institutions with expertise in performing molecular pathology of sarcomas and a list of places and colleagues providing radiosurgery. Therefore, we recommend referring patients with primary malignant tumours to these centres or colleagues. This approach should not be a problem, as in Poland, allocation and free

**Table 5** Recommendations. Imaging diagnostics. Primary benign tumours

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | To further investigate signal intensity measurements on T1-weighted images with and without fat suppression to differentiate spinal haemangiomas from metastases | B | [13] | III | Retrospective |
| 2 | MRI as study with a key role in the diagnosis of benign tumours of the spine In some cases of benign tumours, MRI enables a reliable diagnosis (e.g., stem haemangioma, osteoma, and lipoma). Some tumours may not require contrast examinations due to their characteristic imaging findings but in case of doubt, the examination should be supplemented with contrast, computed tomography, possibly scintigraphy, or even PET | B | [14] | III | Retrospective |
| 3 | To take into account the tumour size, preoperative alkaline phosphatase (ALP) and CT images for distinguishing aggressive osteoblastoma from conventional osteoblastoma | B | [15] | III | Retrospective |

**Table 6** Recommendations. Sarcomas. General diagnostic requirements

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | That medical centres that perform diagnostic and therapeutic procedures on spine sarcomas should have the following organizational possibilities:<br>(1) Staff: oncological surgery specialist/orthopaedist and neurosurgeon with experience in en bloc spine surgery/paediatric surgeon with experience in the treatment of bone sarcomas—on site, clinical oncology specialist—on site, radiotherapy specialist—on site, physiotherapist—on site, psycho-oncologist—at the location<br>(2) Intensive care unit—on site<br>(3) Radiology laboratory (24/7 access)—USG, CT, MRI in a location with the possibility of performing an intraoperative X-ray examination<br>(4) Histopathology laboratory with the possibility of performing an intraoperative examination pathology at the location<br>(5) Possibility of a multidisciplinary consultation (oncologist/orthopaedic surgeon, radiotherapist, clinical oncologist-chemotherapist, pathologist, radiologist) at the centre<br>(6) Possibility of carrying out adjuvant treatment (chemotherapy, radiotherapy with the possibility of IMRT and stereotaxic techniques) at the location or under an agreement with an external centre. Coordination of systemic treatment and radiotherapy must be ensured<br>(7) Possibility to perform cytogenetic and molecular diagnostics—at the location or on the basis of an agreement with an external centre<br>(8) In Poland, it is recommended that patients with bone sarcomas be treated only in specialized reference centres or in units with extensive experience in treating patients with this cancer, where at least 20–25 patients with bone sarcomas are treated annually | C | [1] | V | Expert opinion |

referrals to any institution within the Polish national health service system are protected by the patients' right to freely choose primary care doctors, specialists, hospitals, and medical institutions anywhere in the country. Free referrals within the system are by no means restricted, and patients, regardless of their place of residence in Poland, who are entitled to free services of the national health system (NHS) have the freedom to choose the place and physician for treatment. Additionally, we believe that the allocation of patients with spinal sarcomas and chordomas to

**Table 7** Recommendations. Biopsy

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Spine biopsy should be planned based on at least two out of following three imaging studies: CT, NMR, PET | B | [16] | II | Systematic review of the literature |
| 2 | Biopsy be performed in a centre where definite Enneking-appropriate surgical treatment can be performed if a primary tumour is suspected | B | [17] | II | Systematic review of the literature |
| 3 | Percutaneous is preferred over open biopsy of neoplastic lesions of the spine<br>Percutaneous biopsy is safer than open biopsy and equally effective | A | [18] | I | Retrospective |
| 4 | The diameter of the collected bone cylinder on the percutaneous biopsy of the vertebral lesion should be greater than 2 mm<br>This size ensures the preservation of the bone architecture crucial for histological diagnosis<br>The diagnostic value of percutaneous vertebral biopsy is very high | B | [19, 20] | II/III | Retrospective, prospective |
| 5 | Percutaneous biopsy should be performed under the guidance of a CT scan or ideally under navigation<br>CT allows for more accurate and safer biopsy compared to C-arm navigated biopsy | B | [20] | III | Retrospective |
| 6 | Percutaneous biopsy should be performed, especially for lesions in the anterior column of the spine | B | [20] | III | Retrospective |
| 7 | Biopsy be performed in a centre with full surgical and pathomorphological facilities<br>The accuracy of the biopsy is influenced by the experience of the surgeon performing the procedure and the pathologist assessing the bone tissue, therefore the biopsy should be performed in a centre with full surgical and pathomorphological facilities. Errors, complications, and changes in the course and outcome are two to twelve times greater when the biopsy is done in a referring institution instead of in a treatment centre | B | [20, 21] | III | Retrospective |

**Table 8** Recommendations. Sarcomas. General requirements of histological diagnostics

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | The pathomorphological examination report should be based on the classification of the World Health Organization<br>In the differential diagnosis of small cell neoplasms | B | [35, 36] | II | Systematic review |
| 2 | The differential diagnosis be performed in centres with access to immunohistochemical and cytogenetic tests<br>A differential histological diagnosis is necessary to assess the characteristic translocations | B | [35, 36] | II | Systematic review |

**Table 9** Recommendations. Primary tumours. Surgical treatment. General principles

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | En bloc resection in cases of benign aggressive tumours considered Enneking stage 3 (i.e., osteoblastomas and giant cell tumours) and low-grade malignant tumours considered Enneking stage I A and B, such as chordomas and chondrosarcomas | C | [25] | V | Expert opinion |
| 2 | The Weinstein Boriani Biagnini staging system is a helpful tool in planning of en bloc surgical resection | C | [26, 27] | V | Expert opinion |

**Table 10** Recommendations. Sarcomas. Treatment. General principles

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Combination therapy within established therapeutic protocols for all of the Ewing group's sarcomas and bone sarcomas<br>These tumours are highly malignant neoplasms. The results of surgical treatment alone are poor, with 5-year survival rates less than 20% | A | [37–50] | I | Randomized control study |
| 2 | Surgical treatment of Ewing sarcoma should be preceded by chemotherapy | A | [37–50] | I | Randomized control study |
| 3 | High-dose adjuvant photon/proton radiotherapy of chordomas, chondrosarcomas, and other sarcomas should be used<br>This kind of radiotherapy provides high local control while the late morbidity appears to be acceptable | B | [51] | III | Prospective |
| 4 | Surgical treatment should aim for a cure rather than palliation whenever possible | C | [52] | III | Retrospective comparative study |
| 5 | Periosteal osteosarcoma is the only exception to the use of perioperative chemotherapy | C | [53] | IV | Retrospective |

the recommended centres will not burden colleagues with expertise in oncologic spine surgery, and it is unlikely that these surgeons will be swamped by these additional cases, as these tumours are extremely rare. With the incidence of spinal sarcomas being 0,19–0,38 per 1,000,000 people, only approximately 7–15 new cases can be expected in Poland per year. The slightly higher incidence of spinal chordoma, 1 per 1,000,000 population, means approximately 38 new cases can be expected in Poland [22–24].

The list is not intended to mandate referrals to the recommended places and specialists, especially in regard to surgical management. Additionally, these specialists will not be obliged to accept such referrals. The estimated number of yearly referrals for spinal sarcomas and chordomas should not exceed 50. Thus, even if only a dozen colleagues have expertise in oncologic spine surgery, each one would potentially accept no more than 3–5 cases if the allocation is evenly distributed across the country. These colleagues declared that they are happy to accept such referrals. Conversely, colleagues who did not declare expertise in complex oncologic spine surgery but will eventually gain such skills with increasing experience should not feel an obligation to refer spinal sarcoma/chordoma patients to colleagues renowned for their expertise in oncologic spine surgery. We understand that complex oncologic spine surgery follows the principles of the Weinstein–Boriani–Biagini (WBB) surgical system used for planning en bloc resections of spinal tumours [25–27]. The WBB systems were developed based

**Table 11** Recommendations. Primary malignant tumours. Surgical management

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Enneking marginal and wide resections (Enneking appropriate resections) over intralesional resection<br>Enneking marginal and wide resections result in a lower risk of recurrence at the surgical site and longer survival than "intralesional" excision according to Enneking. Favourable oncological outcomes after en bloc resection may be achieved in terms of recurrence and survival. "Intralesional" procedures (when the surgeon incidentally or intentionally violates the margins of the tumour) worsen the prognosis and recurrence rate | B/C | [54–56] | II/III | Multicentre ambispective cohort analysis, prospective cohort study, retrospective review |
| 2 | Multilevel en bloc spondylectomy performed by experienced surgeons<br>Oncologic resections achieved by multilevel en bloc spondylectomy in experienced hands can lead led to an acceptable survival rate with reasonable local control | C | [57] | IV | Case series |

**Table 12** Recommendations. Sarcomas. Surgical treatment. General principles

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | En bloc resection rather than piecemeal resection even if both have negative margins<br>En bloc resection with tumour-free margins has a lower rate of recurrence than piecemeal resection with negative margins | C | [52] | III | Retrospective comparative study |

on the Enneking principles of four types of surgical margins for musculoskeletal sarcoma [28]. Some may confuse true extralesional en bloc resection according to the WBB/Enneking principles with Tomita's en bloc spondylectomy, which is excision of the whole vertebra in two pieces from the spine, with the cut line dividing the vertebra into two pieces running through the pedicles [29]. An increasing number of colleagues performing spine surgery are skilled in these techniques and apply them for nonneoplastic pathologies of the spine, such as spinal deformities or infections [30, 31]. These skills do not necessarily translate into expertise in truly extralesional resections because the latter may require different combinations of surgical strategies, including combinations of two, three or even more separate routes of surgical access. Only a few colleagues among spine surgeons have expertise in this type of spine surgery due to the extreme rarity of primary malignant spinal tumours. The chance that an average spine surgeon will encounter a patient with spinal sarcoma or chordoma during his or her career is minimal. The majority of excellent spine surgeons will never

**Table 13** Recommendations. Chondrosarcoma. Adjuvant and Standalone radiotherapy

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Adjuvant radiotherapy after complete resection of the tumour<br>Although complete surgical resection is paramount in the management of chondrosarcoma, RT is a useful adjuvant treatment and appears to offer excellent and durable local control when wide surgical resection is difficult to accomplish | B | [58] | III | Retrospective |
| 2 | High-dose proton irradiation rather conventional radiotherapy after maximum resection of the tumour, whenever possible<br>Maximum surgical resection followed by high-dose proton irradiation results in superior results to conventional X-ray treatment of chondrosarcomas of the skull base | B | [59–61] | III | Retrospective |
| 3 | Irradiation in cases of inoperable tumours<br>Evidence suggests that chondrosarcoma is not radioresistant and that irradiation should be considered when surgery would cause major unacceptable morbidity or be technically impossible. Early evidence suggests there may be a role for chemotherapy to supplement the effects of irradiation | B | [62, 63] | III | Retrospective |

**Table 14** Recommendations. Osteosarcoma

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Enneking-appropriate en bloc (EA) resection rather than Enneking-inappropriate (EI) intralesional resection of the tumour<br>There is a significant decrease in recurrence, an increase in survival duration and a decrease in metastasis rate with EA en bloc resection when compared with EI intralesional resection | B/C | [64, 65] | III | Ambispective cohort studies, systematic review with meta-analysis |
| 2 | High-dose proton therapy doses for some patients with unresectable or incompletely resected osteosarcomas<br>Proton therapy delivering high-dose radiotherapy provides locally curative treatment for some patients with inoperable tumours or partially resected tumours | B | [66–68] | III | Retrospective, case control study |
| 3 | Radiotherapy or proton therapy after surgical treatment with positive margins<br>Radiotherapy can help provide local control of osteosarcoma for patients in whom surgical resection with wide, negative margins is not possible. Radiotherapy appears to be more effective in situations in which microscopic or minimal residual disease is being treated | | [69] | III | Retrospective |
| 4 | Discussion with medical oncologist about adjuvant or neoadjuvant chemotherapy<br>The effect of adjuvant and neoadjuvant chemotherapeutics requires further exploration | B | [64] | III | Ambispective cohort studies |

**Table 15** Recommendations. Ewing Sarcoma

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Neoadjuvant chemotherapy<br>Preoperative chemotherapy allows for satisfactory results in terms of relapse-free survival (RFS). Patients with resectable tumours after initial chemotherapy have a low local failure rate. Some studies show however that with preoperative radiotherapy, the local control rate is comparable to that with preoperative (neoadjuvant) chemotherapy. The treatment results are comparable between axial tumours and appendicular tumours | A | [45, 50, 70] | I | Randomized control study, retrospective analysis of randomized control studies |
| 2 | Surgical resection whenever possible and appropriate<br>Compared to stand-alone radiotherapy for locally advanced disease, a surgical procedure allows for better results in terms of local control (LC), but with no difference in overall survival (OS). The risk of local failure is greater for stand-alone radiation than for surgery | A | [49] | I | Retrospective analysis of randomized control studies |
| 3 | Postoperative radiotherapy after intralesional or marginal resections and after wide resection with a poor histologic response<br>Postoperative radiotherapy may improve local control after resections with positive margins or even Enneking wide resections in patients with poor histologic response | A | [45, 71, 72] | I | Retrospective analysis of randomized control studies |
| 4 | Radiotherapy in inoperable cases | A | [50] | I | Retrospective analysis of randomized control studies |

operate on such spinal tumours, except of a few colleagues specializing in complex oncological spine surgery. Our recommendation for Enneking's wide and marginal excision of spinal sarcomas and chordomas implies that surgical treatment should ideally be performed by surgeons with expertise in oncological spine surgery. This in turn imposes that a biopsy be performed by the surgeon operating on the tumour because the biopsy must be performed with the surgery plan in mind, as the biopsy tract will have to be removed en bloc with the tumour. Similarly, we recommend that the histopathological diagnostics of spine lesions suspected to be a primary malignancy be performed in recommended centres with expertise in malignant bone tumours. The list of such centres where a sample can be sent for evaluation as well as instructions on how to maintain and fix the biopsied sample will be included in the appendix to our recommendations.

Malignant spinal tumours, in particular sarcomas, provide a particular diagnostic dilemma due to their variety, with more than 100 histological subtypes that often correspond to different biological behaviours and eventually respond differently to chemotherapeutic agents as well as targeted therapy and immunotherapy [32]. This heterogeneity in classification is accompanied by a broad spectrum of biological behaviour, from locally aggressive and nonmetastatic tumours to tumours that behave relatively indolently in the metastatic state to those that are highly aggressive and rapidly metastasise. Histological evaluations of sarcomas require advanced molecular diagnostics [32, 33].

**Table 16** Recommendations. Chordoma

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Enneking-appropriate resection<br>Enneking-appropriate resection plays a major role in decreasing the risk for local recurrence in patients with chordoma of the mobile spine | B | [73] | II | Multi-institutional retrospective study |
| 2 | Postoperative proton therapy over conventional therapy<br>Postoperative proton therapy has better overall survival results than postoperative conventional photon radiotherapy. The 10-year overall survival rate is also higher for proton therapy than for stereotactic radiotherapy | B | [74, 75] | II | Meta-analysis, retrospective |
| 3 | Aggressive therapy combining resection as radical as possible with postoperative proton or radiotherapy<br>A combination of aggressive surgery and radiotherapy seems to improve the prognoses of suboccipital and cervical chordomas when applied at the patient's first presentation of the disease. Postoperative radiotherapy yields better survival results than salvage radiotherapy in terms of local recurrence | B | [76] | III | Retrospective |
| 4 | High-dose definitive radiation therapy in inoperable cases<br>In certain circumstances where resection of the mobile spine or sacral chordoma may result in significant neurologic or organ dysfunction, patients can be treated definitively with the use of high-dose definitive radiation therapy | B | [77] | III | Retrospective |

**Table 17** Recommendations. Osteoblastoma

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Total excision whenever possible | B | [15] | III | Retrospective |
| 2 | En bloc resection of stage 3 tumours, with intralesional excision allowed for stage 2 lesions<br>Total resection is important as local recurrence was found to be strongly associated with mortality. Subtotal excision together with higher preoperative alkaline phosphatase, and tumour size greater than 3 cm results in a higher relapse rate | B | [15, 78–80] | III | Retrospective |
| 3 | Adjuvant radiotherapy when en bloc or total resection is not feasible or requires unacceptable functional sacrifices<br>Radiotherapy seems to be an effective adjuvant treatment when total resection is not feasible | B | [78] | III | Retrospective |

**Table 18** Recommendations. Solitary plasmocytoma

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Definite radiotherapy as the treatment of choice<br>Stand-alone radiotherapy achieves very good results in terms of local control. Chemotherapy and/or novel therapies should be investigated for bone or bulky extramedullary tumours | B | [81–83] | III | Retrospective |

**Table 19** Recommendations. Giant cell tumour

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Surgical treatment (curettage or en bloc resection) as the mainstay of therapy | B | [84] | III | Case control study |
| 2 | Denosumab as the treatment of choice for locally advanced tumours | B | [85–88] | III | Prospective comparative study |
| 3 | Considering neoadjuvant therapy with denosumab to achieve radical surgical treatment | B | [86–88] | III | Prospective comparative study |

**Table 20** Recommendations. Haemangioma with clinical manifestations

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Vertebroplasty for the treatment of tumours with clinical manifestations | C | [89] | IV | Case series |
| 2 | Considering radiotherapy in some cases<br>Radiotherapy is safe and effective for pain relief in the treatment of spinal haemangioma. Total doses of at least 34 Gy achieve the best symptomatic response | B | [90] | III | Retrospective |
| 3 | Radical surgical resection for haemangiomas with an extraosseous extension causing neurological symptoms<br>Local recurrence of the tumour after subtotal resection has been reported, and adjuvant radiotherapy makes a second surgery difficult | C | [91] | IV | Retrospective short case series |

**Table 21** Recommendations. Osteoid osteoma

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Conservative treatment<br>Osteoid osteoma can be treated conservatively. Surgical excision (curettage) was considered the gold standard in the past but is no longer attractive today due to its invasiveness. Surgical resection should be taken into consideration as an option when the results of conservative treatment are poor | A | [92] | I | Systematic review |
| 2 | Surgical resection, radiofrequency ablation, percutaneous laser, and cryoablation in patients harbouring painful spinal osteoid osteoma or when the results of conservative treatment are poor | B | [93–96] | III | Case series |

**Table 22** Recommendations. Osteochondroma

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Complete resection of the cartilaginous cap of the tumour | B | [97] | III | Case control, systematic review |

Advanced molecular diagnostics of rare musculoskeletal tumours, especially sarcomas, are available in very few places dispersed across Poland. This is also the case in other European countries, as documented by the EPAAC through an assessment of the quality of cancer care in Europe [1]. That is why in many countries, there is a trend to concentrate expertise for certain tumour types, including sarcomas, in dedicated centres or units [1].

In Poland, there is a Department of Soft Tissue, Bone Sarcoma and Melanoma at the Maria Sklodowska-Curie Institute Oncology Centre in Warsaw dedicated to the complex management of sarcomas. This department covers the majority of sarcoma cases in regard to molecular diagnostics and surgical treatment in Poland. However, the department mostly encounters only appendicular sarcomas, while spinal sarcomas are randomly operated on elsewhere across the country, often without a preceding biopsy or even radiological diagnosis or radiological suspicion of sarcoma. Therefore, most if not all spinal sarcomas are not operated on compliantly with the WBB/Enneking principles of extralesional excision. Once the preliminary histology of the operated spinal tumour confirms or suggests sarcoma, the sample may be sent for further in-depth diagnosis to another institution with better facilities and expertise in molecular pathology. Sometimes the sample may circulate from institution to institution before it reaches one that eventually establishes a thorough molecular diagnosis. To ensure a timely histological diagnosis and prevent patients from receiving an incomplete diagnosis of sarcoma, we identified all institutions and colleagues in Poland with expertise in molecular pathology techniques for sarcomas. These institutions will be listed in the appendix to the recommendations. Although few exist in the country, these institutions are able to cover the histological diagnostics of all spinal and appendicular sarcomas occurring in Poland. The EPAAC expert group recommends that for an institution to be considered a sarcoma centre, it should treat at least 100 new sarcoma patients (both soft tissue and bone) per year [1]. Similarly, guidance from the National Institute for Health and Care Excellence (NICE) in England and Wales states that multidisciplinary teams (MDTs) managing either soft tissue sarcoma or bone sarcoma should manage the care of at least 100 new patients per year (100 soft tissue and 50 bone sarcomas if the MDT manages both types) [34].

**Table 23** Recommendations. Aneurysmal bone cysts

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Selective arterial embolization as the first treatment option for spine aneurysmal bone cyst without neurologic deficit, pathological fracture or spinal instability<br>This can be followed by surgery in case of recurrence/ineffective treatment | B | [98] | III | Retrospective study |
| 2 | Complete intralesional excision as the therapy of choice in cases of neurologic involvement, pathologic fracture, or local recurrence or when embolization is technically impossible after embolization procedures<br>Remark: radical surgical excision or en bloc resection are correlated with better prognosis for local tumour control with significantly lower recurrence rates, especially when combined with adjunctive therapies such as cryotherapy, phenol, or adjuvant radiotherapy. The resulting recurrence rates are as follows, ranked from highest to lowest: isolated Surgiflo injection into the lesion, decompression/laminectomy, partial excision/resection, and curettage alone. Primary or adjuvant radiotherapy may be an effective and safe treatment option for persistent or recurrent aneurysmal bone cysts | B | [98–102] | III | Retrospective systematic review |

**Table 24** Recommendations. Giant cell tumours

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Complete surgical resection whenever possible, particularly if neurologic impairment is present<br>En bloc resection with wide/marginal margins should be performed when technically feasible because it is associated with decreased local recurrence rates. Intralesional resection is associated with increased local recurrence rates, and mortality correlates with local recurrence | B | [103, 104] | III | Ambispective observational study |
| 2 | Denosumab as neoadjuvant or adjuvant therapy when Enneking-appropriate resection is not possible<br>Denosumab alone is effective in relieving pain, increasing ossification and sometimes reducing the tumour volume. This treatment can be considered when radical surgical treatment is not possible due to associated unacceptable morbidity or loss of function | B | [105] | III | Prospective study |

**Table 25** Recommendations. Fibrous dysplasia

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Treatment with conventional surgical procedures including internal fixation | B | [106] | III | Literature review |

**Table 26** Recommendations. Langerhans cell histiocytosis

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *We recommend* | | | | | |
| 1 | Individualised approaches when establishing therapeutic management<br>The spectrum of therapeutic possibilities is wide and, after the exclusion of a malignant lesion, extends from nonsurgical treatment to alternative administrations of corticosteroids, curettage, replacement of the defect with bone grafts, and even en bloc surgical removal | C | [107–109] | IV | Case series, review of case series |

Therefore, we recommend sending biopsied and intraoperative samples suspected of being spinal sarcoma to the institutions listed in the appendix. This is in accordance with the recommendation of the European Cancer Organization (ECCO) expert group, who stresses that a diagnosis must only be made in dedicated sarcoma centres [1]. In addition, we added instructions to the appendix on how samples from tumours suspected to be a sarcoma should be fixed immediately after harvesting in the operating room.

Only two recommendations were placed on the discrepancy list (Table 28). These recommendations refer to emergency/urgent decompression of the spinal canal to counteract irreversible neurologic deficits in cases where no histological diagnosis was obtained. As everyday practice proves, emergency decompression surgeries are not uncommon in spinal tumours. Urgent or emergency decompression does not conflict with the principles of treatment of spinal tumours as long as the tumour is a metastasis. However, such decompression may conflict with the treatment principles when a tumour appears to be a primary tumour, especially haematopoietic tumours. Surgical treatment of haematopoietic tumours has no proven benefit compared with medical treatment, which usually provides excellent long-term outcomes. The view of some medical colleagues in the group clashed with the views of surgical colleagues. The first view stressed that surgery on haematopoietic malignancies of the spine can reduce or even deprive patients of a chance for a complete cure, even if adequate medical treatment is continued after the operation. The second view noted the impact of permanent complete or severe neurological deficits on quality of life, even if the patient receives state-of-the-art medical treatment. Whether patients with spinal tumours and a risk of permanent neurological deficit should undergo surgery without a biopsy should be discussed with the patient.

The majority of recommendations developed were graded as B and C, while the levels of the identified sources of evidence received grades of II–III, especially in regard to primary malignant spinal tumours. The rarity of these tumours is responsible for the paucity of data regarding their management and lack of higher levels of evidence usually achieved through high-quality therapeutic studies including larger numbers of analysed patients.

**Table 27** Recommendations. Metastases

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| *Scoring systems and diagnostics* | | | | | |
| *We recommend* | | | | | |
| 1 | The final decision for treating patients with spinal metastases should be made based on the prognostic scales and individual assessment results in each case<br>All widespread scoring systems to estimate both overall survival and tumour-specific survival for patients undergoing surgical treatment for metastatic spine disease have similar efficacy. There is no clear evidence of the superiority of one system | B/C | [110, 111] | III | Literature review, retrospective |
| 2 | The spinal instability neoplastic score (SINS) should be used to assess spinal instability in cases with neoplastic involvement of the spine<br>SINS gives reliable indications for spinal instability surgery in patients with metastatic disease of the spine | B | [112] | III | Retrospective |
| 3 | The national outcomes measurement system (NOMS) should be used to facilitate decision-making and can optimize patient care | C | [113] | V | Expert opinion |
| 4 | Complete radiological diagnostics (skull radiographs, computed tomography of the chest, abdomen and pelvis) should be performed, with a panel of oncological and haematological markers before bone biopsy in patients with suspected metastatic lesions of an unknown starting point | B | [114] | III | Retrospective |
| *Metastases. Use of steroids in spinal cord compression* | | | | | |
| *We recommend* | | | | | |
| 1 | Short-term salvage use of steroids in metastatic spinal cord compression (MSCC) before surgery in cases with rapid worsening or severe neurological deficits<br>The optimal steroid dose is unknown, with one small trial demonstrating no significant difference in efficacy between high and low doses of dexamethasone. High-dose regimens may have a higher risk of steroid-related adverse effects and thus, whether the risks of high-dose dexamethasone regimens outweigh the benefits should be considered | A/B | [115, 116] | II | Randomized control study, literature review |
| 2 | Chronic steroid therapy is not recommended to improve neurological function or reduce pain | B | [117] | II | Literature review |
| *Metastases. Surgical treatment* | | | | | |
| *We recommend* | | | | | |
| 1 | The least invasive procedures with the use of minimally invasive techniques sufficient to provide patients with pain reduction, decompression of nerve structures and restoration of stability | B | [118–120] | III | Retrospective |
| 2 | Minimally invasive fixation or augmentation of the vertebral body in the event of a pathological fracture associated with radiotherapy | B | [121] | III | Retrospective |
| 3 | En bloc resection only for carefully selected metastatic lesions such as hormone-secreting tumours and solitary radioresistant tumours, but these procedures must be considered in the context of the patient's systemic disease status and the morbidity of the surgery<br>Total en bloc resection may have narrow indications for carefully selected cases of types 3, 4, and 5 lesions and relative indications for type 1, 2, and 6 lesions according to Tomita's surgical classification of spinal tumour | B | [122–124] | III | Literature review, retrospective |
| 4 | Cement augmentation of pathologically fractured vertebral bodies in the course of haematological neoplasms | B | [125, 126] | III | Literature review |
| 5 | Decompression of the spinal cord in cases of increasing neurological deficits within 48 h | B | [127] | III | Retrospective |
| 6 | Cautious use of surgical treatment for patients with complete paralysis and dysfunction of the sphincters | B | [128] | III | Retrospective |

**Table 27** (continued)

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| 7 | Composite instrumentation of the spine<br>In contrast to metal implants, composite implants eliminate artefacts and therefore allow for precise planning with radiotherapy, making imaging more effective | B | [129–135] | III | Retrospective |
| 8 | No bone grafting in patients who have undergone resection of metastatic tumours | B | [136] | III | Retrospective |
| 9 | Preoperative embolization of highly vascularized tumours (kidney cancer, thyroid cancer, pheochromocytoma) | B | [137] | III | Retrospective |
| *Radiotherapy. Metastases*<br>*We recommend* | | | | | |
| 1 | Radiosurgery when available rather than classic radiotherapy as radiation therapy for spinal metastases, regardless of if used stand-alone or in combination with surgery<br>Radiosurgery is safe and does not increase the risk of complications in relation to palliative radiotherapy. Radiosurgery has a longer analgesic effect than conventional palliative radiotherapy | A | [138–143] | I | Randomized control study |
| 2 | Stand-alone radiosurgery as the method of choice in diagnosing up to 3 metastatic lesions of the spine without signs of instability or neurological deficits in patients with a survival prognosis of > 3 months | B | [144] | II | Systematic review of level II and III studies |
| | Radiosurgery of several metastatic lesions prolongs the survival of patients in relation to palliative treatment | A | [145] | I | Randomized control study |
| 3 | Repeat radiosurgery as a treatment option in the event of local recurrence after radiosurgery or palliative radiotherapy in patients disqualified from surgery<br>Radiosurgery has a very good therapeutic effect and is understood to stop the growth of the treated focus, both when used alone and in combination with surgical treatment | B | [146] | II | Systematic review of level III studies, case series |
| 4 | Radiotherapy of the spine as a treatment option in patients with spine metastases when radiosurgery is not available or patients disqualified from radiosurgery and/or surgical decompression and recommended to abandon EBRT by a radiotherapist | B | [147] | II | Systematic review of level II and III studies |
| | A single dose of 10 Gy is not associated with a greater risk of loss of mobility than a 20 Gy regimen administered in 5 fractions in the group of patients not qualified for decompression | A | [148] | I | Randomized control study |
| 5 | Combination of surgical decompression/separation surgery with radiosurgery, or classic radiotherapy (EBRT) when the former is not available<br>Radiotherapy in combination with surgical decompression improves local control in patients treated for compression of the spine. Radiosurgery allows for less invasive surgical procedures and improves the quality of life of patients with spinal cord compression Radiosurgery is a safer therapeutic option than conventional radiotherapy in regard to postoperative wound healing | B | [149–155] | I/II | Randomized control study, systematic reviews, systematic review of level II and III studies, prospective |
| | The operation performed after radiosurgery is not associated with more frequent complications<br>Performing the procedure in a short time after radiosurgery (less than 7 days) is safe and does not increase the rate of complications<br>Radiosurgery can increase the safety of the subsequent surgery by reducing tumour bleeding | C | [156–158] | III | Systematic review of level III studies<br>Retrospective comparative study,<br>Expert opinion<br>Prospective study<br>Large retrospective study<br>Prospective study |

**Table 27** (continued)

| NR | Recommendation | Strength of the recommendation | Source of data supporting the recommendation | Study level of the source | Study type of the source |
|---|---|---|---|---|---|
| 6 | Conventional radiotherapy should be used optimally, after a min of 2 weeks after the surgery to ensure wound healing<br>Using this method too early may result in the necessity to remove the implants due to inflammation. Radiosurgery can shorten this time | C | [153, 159, 160] | III | Systematic review of level III studies |
| 7 | Carbon instrumentation if surgical treatment was performed before radiosurgery<br>The use of carbon implants enables the precise and more effective application of radiation treatment techniques and the planning of radiosurgery | C | [161] | III | Case series |

**Table 28** Discrepancies

| | | |
|---|---|---|
| 1 | Indications for emergency or urgent surgical decompression to counteract irreversible neurologic deficits in patients with confirmed haematopoietic tumours should be established individually after a discussion with the patient and with the opinion that haematopoietic tumours should undergo radiotherapy and/or systemic treatment kept in mind | No evidence were yielded from the literature regarding survival and curability after surgical decompression of haematopoietic tumours with adjuvant therapy verses primarily systemic therapy |
| 2 | Decompression of the spinal canal in patients with tumours of unknown origin that threaten severe neurological deficits without biopsy should be individually discussed with the patient<br>Patients may have a reduced chance for being cured if the histological examination finds that the tumour is the primary tumour | See treatment recommendation for primary tumours in Table 2 |

## Conclusions

The developed recommendations together with the national network of expertise should optimize the management of patients with spinal tumours, especially those with rare malignancies, and optimize their referral and allocation within the Polish NHS.

**Authors' contribution** MA wrote the manuscript, MA, GR, KD, RP were chairs of the Recommendation Development Group, formulated recommendations, supervised voting, AK, DM, DK, GR, GL, GG, MH, JW, JP, ŁD, MA, MT, PT, RM, TŁ, ZR: literature search, formulation of recommendations.

## Declarations

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## References

1. Andritsch E, Beishon M, Bielack S et al (2017) ECCO essential requirements for quality cancer care: soft tissue sarcoma in adults and bone sarcoma. A critical review. Crit Rev Oncol Hematol 110:94–105. https://doi.org/10.1016/j.critrevonc.2016.12.002
2. Grades of recommendation. https://www.spine.org/Research-Clinical-Care/Research/Grades-of-Recommendation
3. https://www.spine.org/Portals/0/assets/downloads/ResearchClinicalCare/LevelsOfEvidence.pdf
4. Buhmann S, Becker C, Duerr HR, Reiser M, Baur-Melnyk A (2009) Detection of osseous metastases of the spine: comparison of high resolution multi-detector-CT with MRI. Eur J Radiol 69:567–573. https://doi.org/10.1016/j.ejrad.2007.11.039
5. Sutcliffe P, Connock M, Shyangdan D, Court R, Kandala NB, Clarke A (2013) A systematic review of evidence on malignant spinal metastases: natural history and technologies for

identifying patients at high risk of vertebral fracture and spinal cord compression. Health Technol Assess 17:1–274. https://doi.org/10.3310/hta17420
6. Algra PR, Bloem JL, Tissing H, Falke TH, Arndt JW, Verboom LJ (1991) Detection of vertebral metastases: comparison between MR imaging and bone scintigraphy. Radiographics 11:219–232. https://doi.org/10.1148/radiographics.11.2.2028061
7. Kim JK, Learch TJ, Colletti PM, Lee JW, Tran SD, Terk MR (2000) Diagnosis of vertebral metastasis, epidural metastasis, and malignant spinal cord compression: are T1-weighted sagittal images sufficient? Magn Reson Imaging 18:819–824. https://doi.org/10.1016/s0730-725x(00)00181-8
8. Venkitaraman R, Sohaib SA, Barbachano Y, Parker CC, Khoo V, Huddart RA, Horwich A, Dearnaley DP (2007) Detection of occult spinal cord compression with magnetic resonance imaging of the spine. Clin Oncol 19:528–531. https://doi.org/10.1016/j.clon.2007.04.001
9. Bayley A, Milosevic M, Blend R, Logue J, Gospodarowicz M, Boxen I, Warde P, McLean M, Catton C, Catton P (2001) A prospective study of factors predicting clinically occult spinal cord compression in patients with metastatic prostate carcinoma. Cancer 92:303–310. https://doi.org/10.1002/1097-0142(20010715)92:2%3c303::aid-cncr1323%3e3.0.co;2-f
10. Bilsky MH, Laufer I, Fourney DR, Groff M, Schmidt MH, Varga PP, Vrionis FD, Yamada Y, Gerszten PC, Kuklo TR (2010) Reliability analysis of the epidural spinal cord compression scale. J Neurosurg Spine 13:324–328. https://doi.org/10.3171/2010.3.spine09459
11. Fourney DR, Frangou EM, Ryken TC et al (2011) Spinal instability neoplastic score: an analysis of reliability and validity from the spine oncology study group. J Clin Oncol 29:3072–3077. https://doi.org/10.1200/jco.2010.34.3897
12. Fisher CG, Schouten R, Versteeg AL et al (2014) Reliability of the spinal instability neoplastic score (SINS) among radiation oncologists: an assessment of instability secondary to spinal metastases. Radiat Oncol 9:69. https://doi.org/10.1186/1748-717x-9-69
13. Shi YJ, Li XT, Zhang XY, Liu YL, Tang L, Sun YS (2017) Differential diagnosis of hemangiomas from spinal osteolytic metastases using 3.0 T MRI: comparison of T1-weighted imaging, chemical-shift imaging, diffusion-weighted and contrast-enhanced imaging. Oncotarget 8:71095
14. Amini B, Patel K, Westmark RM, Westmark KD, Gonzalez A (2020) 27 approach to the solitary vertebral lesion on magnetic resonance imaging. Radiol Key. https://doi.org/10.1055/b-0040-17686327
15. Yin H, Zhou W, Yu H, Li B, Zhang D, Wu Z, Liu T, Xiao J (2014) Clinical characteristics and treatment options for two types of osteoblastoma in the mobile spine: a retrospective study of 32 cases and outcomes. Eur Spine J 23:411–416. https://doi.org/10.1007/s00586-013-3049-1
16. Veltri A, Bargellini I, Giorgi L, Almeida PAMS, Akhan O (2017) CIRSE guidelines on percutaneous needle biopsy (PNB). CardioVasc Interv Radiol 40:1501–1513. https://doi.org/10.1007/s00270-017-1658-5
17. Tehranzadeh J, Tao C, Browning CA (2007) Percutaneous needle biopsy of the spine. Acta Radiol 48:860–868. https://doi.org/10.1080/02841850701459783
18. Ravikanth R (2020) Diagnostic yield and technical aspects of fluoroscopy-guided percutaneous transpedicular biopsy of the spine: a single-center retrospective analysis of outcomes and review of the literature. J Craniovertebr Junction Spine 11:93–98. https://doi.org/10.4103/jcvjs.JCVJS_43_20
19. Schweitzer ME, Gannon FH, Deely DM, O'Hara BJ, Juneja V (1996) Percutaneous skeletal aspiration and core biopsy: complementary techniques. Am J Roentgenol 166:415–418. https://doi.org/10.2214/ajr.166.2.8553958
20. Liang Y, Liu P, Jiang LB, Wang HL, Hu AN, Zhou XG, Li XL, Lin H, Wu D, Dong J (2019) Value of CT-guided core needle biopsy in diagnosing spinal lesions: a comparison study. Orthop Surg 11:60–65. https://doi.org/10.1111/os.12418
21. Springfield DS, Rosenberg A (1996) Editorial—biopsy. J Bone Jt Surg 78:639–643. https://doi.org/10.2106/00004623-199605000-00001
22. Mukherjee D, Chaichana KL, Gokaslan ZL, Aaronson O, Cheng JS, McGirt MJ (2011) Survival of patients with malignant primary osseous spinal neoplasms: results from the Surveillance, Epidemiology, and End Results (SEER) database from 1973 to 2003. J Neurosurg Spine 14:143–150. https://doi.org/10.3171/2010.10.spine10189
23. Oitment C, Bozzo A, Martin AR, Rienmuller A, Jentzsch T, Aoude A, Thornley P, Ghert M, Rampersaud R (2021) Primary sarcomas of the spine: population-based demographic and survival data in 107 spinal sarcomas over a 23-year period in Ontario, Canada. Spine J 21:296–301. https://doi.org/10.1016/j.spinee.2020.09.004
24. Heery CR (2016) Chordoma: the quest for better treatment options. Oncol Ther 4:35–51. https://doi.org/10.1007/s40487-016-0016-0
25. Boriani S (2018) En bloc resection in the spine: a procedure of surgical oncology. J Spine Surg 4:668–676. https://doi.org/10.21037/jss.2018.09.02
26. Boriani S, Weinstein JN, Biagini R (1997) Primary bone tumors of the spine terminology and surgical staging. Spine 22:1036–1044. https://doi.org/10.1097/00007632-199705010-00020
27. Chan P, Boriani S, Fourney DR et al (2009) An assessment of the reliability of the enneking and Weinstein–Boriani–Biagini classifications for staging of primary spinal tumors by the Spine Oncology Study Group. Spine 34:384–391. https://doi.org/10.1097/brs.0b013e3181971283
28. Enneking WF, Spanier SS, Goodman MA (1980) A system for the surgical staging of musculoskeletal sarcoma. Clin Orthop Relat Res 153:106–120. https://doi.org/10.1097/00003086-198011000-00013
29. Tomita K, Kawahara N, Baba H, Tsuchiya H, Fujita T, Toribatake Y (1997) Total en bloc spondylectomy. A new surgical technique for primary malignant vertebral tumors. Spine 22:324–333. https://doi.org/10.1097/00007632-199702010-00018
30. Wang Y, Zhang Y, Zhang X, Huang P, Xiao S, Wang Z, Liu Z, Liu B, Lu N, Mao K (2008) A single posterior approach for multilevel modified vertebral column resection in adults with severe rigid congenital kyphoscoliosis: a retrospective study of 13 cases. Eur Spine J 17:361–372. https://doi.org/10.1007/s00586-007-0566-9
31. Wang Y, Zhang YG, Zhang XS, Wang Z, Mao K, Chen C, Zheng GQ, Li G, Wood KB (2009) Posterior-only multilevel modified vertebral column resection for extremely severe Pott's kyphotic deformity. Eur Spine J 18:1436–1441. https://doi.org/10.1007/s00586-009-1067-9
32. Grunewald TG, Alonso M, Avnet S et al (2020) Sarcoma treatment in the era of molecular medicine. EMBO Mol Med 12:e11131. https://doi.org/10.15252/emmm.201911131
33. Brown HK, Schiavone K, Gouin F, Heymann MF, Heymann D (2018) Biology of bone sarcomas and new therapeutic developments. Calcif Tissue Int 102:174–195. https://doi.org/10.1007/s00223-017-0372-2
34. National Institute of Health and Care Excellence (2006) Improving outcomes for people with sarcoma. https://www.nice.org.uk/guidance/csg9/resources/improving-outcomes-for-people-with-sarcoma-update-773381485

35. WHO Classification of Tumours (2020) Bone and soft tissue tumours. IARC Press, Lyon
36. Casali PG, Bielack S, Abecassis N et al (2018) Bone sarcomas: ESMO-PaedCan-EURACAN clinical practice guidelines for diagnosis, treatment and follow-up. Ann Oncol 29:iv79–iv95. https://doi.org/10.1093/annonc/mdy310
37. Marina NM, Smeland S, Bielack SS et al (2016) Comparison of MAPIE versus MAP in patients with a poor response to preoperative chemotherapy for newly diagnosed high-grade osteosarcoma (EURAMOS-1): an open-label, international, randomised controlled trial. Lancet Oncol 17:1396–1408. https://doi.org/10.1016/s1470-2045(16)30214-5
38. Whelan JS, Bielack SS, Marina N et al (2015) EURAMOS-1, an international randomised study for osteosarcoma: results from pre-randomisation treatment. Ann Oncol 26:407–414. https://doi.org/10.1093/annonc/mdu526
39. Ferrari S, Smeland S, Mercuri M et al (2005) Neoadjuvant chemotherapy with high-dose Ifosfamide, high-dose methotrexate, cisplatin, and doxorubicin for patients with localized osteosarcoma of the extremity: a joint study by the Italian and Scandinavian Sarcoma Groups. J Clin Oncol 23:8845–8852. https://doi.org/10.1200/jco.2004.00.5785
40. Bajpai J, Chandrasekharan A, Talreja V, Simha V, Chandrakanth MV, Rekhi B, Khurana S, Khan A, Vora T, Ghosh J, Banavali SD, Gupta S (2017) Outcomes in non-metastatic treatment naive extremity osteosarcoma patients treated with a novel non-high dosemethotrexate-based, dose-dense combination chemotherapy regimen 'OGS-12.' Eur J Cancer 85:49–58. https://doi.org/10.1016/j.ejca.2017.08.013
41. Piperno-Neumann S, Ray-Coquard I, Occean BV et al (2020) Results of API–AI based regimen in osteosarcoma adult patients included in the French OS2006/Sarcome-09 study. Int J Cancer 146:413–423. https://doi.org/10.1002/ijc.32526
42. Ferrari S, Bielack SS, Smeland S et al (2018) EURO-BOSS: a European study on chemotherapy in bone-sarcoma patients aged over 40: outcome in primary high-grade osteosarcoma. Tumori J 104:30–36. https://doi.org/10.5301/tj.5000696
43. Bielack SS, Smeland S, Whelan JS et al (2015) Methotrexate, doxorubicin, and cisplatin (MAP) plus maintenance pegylated interferon alfa-2b versus MAP alone in patients with resectable high-grade osteosarcoma and good histologic response to preoperative MAP: rirst results of the EURAMOS-1 good response randomized controlled trial. J Clin Oncol 33:2279–2287. https://doi.org/10.1200/JCO.2014.60.0734
44. van Doorninck JA, Ji L, Schaub B, Shimada H, Wing MR, Krailo MD, Lessnick SL, Marina N, Triche TJ, Sposto R, Womer RB, Lawlor ER (2010) Current treatment protocols have eliminated the prognostic advantage of type 1 fusions in Ewing sarcoma: a report from the Children's Oncology Group. J Clin Oncol 28:1989–1994. https://doi.org/10.1200/JCO.2009.24.5845
45. Schuck A, Ahrens S, Paulussen M, Kuhlen M, Könemann S, Rübe C, Winkelmann W, Kotz R, Dunst J, Willich N, Jürgens H (2003) Local therapy in localized Ewing tumors: results of 1058 patients treated in the CESS 81, CESS 86, and EICESS 92 trials. Int J Radiat Oncol Biol Phys 55:168–177. https://doi.org/10.1016/s0360-3016(02)03797-5
46. Womer RB, West DC, Krailo MD, Dickman PS, Pawel BR, Grier HE, Marcus K, Sailer S, Healey JH, Dormans JP, Weiss AR (2012) Randomized controlled trial of interval-compressed chemotherapy for the treatment of localized Ewing sarcoma: a report from the Children's Oncology Group. J Clin Oncol 30:4148–4154. https://doi.org/10.1200/JCO.2011.41.5703
47. Le Deley MC, Paulussen M, Lewis I et al (2014) Cyclophosphamide compared with ifosfamide in consolidation treatment of standard-risk Ewing sarcoma: results of the randomized noninferiority Euro-EWING99-R1 trial. J Clin Oncol 32:2440–2448. https://doi.org/10.1200/jco.2013.54.4833
48. Brennan B, Kirton L, Marec-Berard P, Martin-Broto J, Gelderblom H, Gaspar N, Strauss SJ, Sastre Urgelles A, Anderton J, Laurence V, Whelan J, Wheatley K (2020) Comparison of two chemotherapy regimens in Ewing sarcoma (ES): overall and subgroup results of the Euro Ewing 2012 randomized trial (EE2012). J Clin Oncol 38:11500. https://doi.org/10.1200/jco.2020.38.15_suppl.11500
49. DuBois SG, Krailo MD, Gebhardt MC et al (2014) Comparative evaluation of local control strategies in localized Ewing sarcoma of bone: a report from the Children's Oncology Group. Cancer 121:467–475. https://doi.org/10.1002/cncr.29065
50. Schuck A, Ahrens S, von Schorlemer I, Kuhlen M, Paulussen M, Hunold A, Gosheger G, Winkelmann W, Dunst J, Willich N, Jürgens H (2005) Radiotherapy in Ewing tumors of the vertebrae: treatment results and local relapse analysis of the CESS 81/86 and EICESS 92 trials. Int J Radiat Oncol Biol Phys 63:1562–1567. https://doi.org/10.1016/j.ijrobp.2005.05.036
51. DeLaney TF, Liebsch NJ, Pedlow FX et al (2014) Long-term results of phase II study of high dose photon/proton radiotherapy in the management of spine chordomas, chondrosarcomas, and other sarcomas. J Surg Oncol 110:115–122. https://doi.org/10.1002/jso.23617
52. Talac R, Yaszemski MJ, Currier BL, Fuchs B, Dekutoski MB, Kim CW, Sim FH (2002) Relationship between surgical margins and local recurrence in sarcomas of the spine. Clin Orthop Relat Res 397:127–132. https://doi.org/10.1097/00003086-200204000-00018
53. Ruengwanichayakun P, Gambarotti M, Frisoni T, Gibertoni D, Guaraldi F, Sbaraglia M, Dei Tos AP, Picci P, Righi A (2019) Parosteal osteosarcoma: a monocentric retrospective analysis of 195 patients. Hum Pathol 91:11–18. https://doi.org/10.1016/j.humpath.2019.05.009
54. Fisher CG, Saravanja DD, Dvorak MF, Rampersaud YR, Clarkson PW, Hurlbert J, Fox R, Zhang H, Lewis S, Riaz S, Ferguson PC, Boyd MC (2011) Surgical management of primary bone tumors of the spine. Spine 36:830–836. https://doi.org/10.1097/brs.0b013e3181e502e5
55. Amendola L, Cappuccio M, De Iure F, Bandiera S, Gasbarrini A, Boriani S (2014) En bloc resections for primary spinal tumors in 20 years of experience: effectiveness and safety. Spine J 14:2608–2617. https://doi.org/10.1016/j.spinee.2014.02.030
56. Sciubba DM, Ramos RDLG, Goodwin CR, Xu R, Bydon A, Witham TF, Gokaslan ZL, Wolinsky JP (2016) Total en bloc spondylectomy for locally aggressive and primary malignant tumors of the lumbar spine. Eur Spine J 25:4080–4087. https://doi.org/10.1007/s00586-016-4641-y
57. Luzzati AD, Shah S, Gagliano F, Perrucchini G, Scotto G, Alloisio M (2015) Multilevel en bloc spondylectomy for tumors of the thoracic and lumbar spine is challenging but rewarding. Clin Orthop Relat Res 473:858–867. https://doi.org/10.1007/s11999-014-3578-x
58. Goda JS, Ferguson PC, O'Sullivan B, Catton CN, Griffin AM, Wunder JS, Bell RS, Kandel RA, Chung PW (2011) High-risk extracranial chondrosarcoma: long-term results of surgery and radiation therapy. Cancer 117:2513–2519. https://doi.org/10.1002/cncr.25806
59. Noël G, Feuvret L, Ferrand R, Boisserie G, Mazeron JJ, Habrand JL (2004) Radiotherapeutic factors in the management of cervical-basal chordomas and chondrosarcomas. Neurosurgery 55:1252–1262. https://doi.org/10.1227/01.neu.0000143330.30405.aa

60. Ares C, Hug EB, Lomax AJ, Bolsi A, Timmermann B, Rutz HP, Schuller JC, Pedroni E, Goitein G (2009) Effectiveness and safety of spot scanning proton radiation therapy for chordomas and chondrosarcomas of the skull base: first long-term report. Int J Radiat Oncol Biol Phys 75:1111–1118. https://doi.org/10.1016/j.ijrobp.2008.12.055
61. Hug EB, Loredo LN, Slater JD, Devries A, Grove RI, Schaefer RA, Rosenberg AE, Slater JM (1999) Proton radiation therapy for chordomas and chondrosarcomas of the skull base. J Neurosurg 91:432–439. https://doi.org/10.3171/jns.1999.91.3.0432
62. Krochak R, Harwood AR, Cummings BJ, Quirt IC (1983) Results of radical radiation for chondrosarcoma of bone. Radiother Oncol 1:109–115. https://doi.org/10.1016/s0167-8140(83)80014-0
63. McNaney D, Lindberg RD, Ayala AG, Barkley HT, Hussey DH (1982) Fifteen year radiotherapy experience with chondrosarcoma of bone. Int J Radiat Oncol Biol Phys 8:187–190. https://doi.org/10.1016/0360-3016(82)90512-0
64. Dekutoski MB, Clarke MJ, Rose P et al (2016) Osteosarcoma of the spine: prognostic variables for local recurrence and overall survival, a multicenter ambispective study. J Neurosurg Spine 25:59–68. https://doi.org/10.3171/2015.11.spine15870
65. Pombo B, Ferreira AC, Cardoso P, Oliveira A (2019) Clinical effectiveness of Enneking appropriate versus Enneking inappropriate procedure in patients with primary osteosarcoma of the spine: a systematic review with meta-analysis. Eur Spine J 29:238–247. https://doi.org/10.1007/s00586-019-06099-7
66. Ciernik IF, Niemierko A, Harmon DC, Kobayashi W, Chen Y-L, Yock TI, Ebb DH, Choy E, Raskin KA, Liebsch N, Hornicek FJ, Delaney TF (2011) Proton-based radiotherapy for unresectable or incompletely resected osteosarcoma. Cancer 117:4522–4530. https://doi.org/10.1002/cncr.26037
67. Matsunobu A, Imai R, Kamada T, Imaizumi T, Tsuji H, Tsujii H, Shioyama Y, Honda H, Tatezaki SI (2012) Impact of carbon ion radiotherapy for unresectable osteosarcoma of the trunk. Cancer 118:4555–4563. https://doi.org/10.1002/cncr.27451
68. Spałek MJ, Poleszczuk J, Czarnecka AM et al (2021) Radiotherapy in the management of pediatric and adult osteosarcomas: a multi-institutional cohort analysis. Cells 10:366. https://doi.org/10.3390/cells10020366
69. DeLaney TF, Park L, Goldberg SI, Hug EB, Liebsch NJ, Munzenrider JE, Suit HD (2005) Radiotherapy for local control of osteosarcoma. Int J Radiat Oncol Biol Phys 61:492–498. https://doi.org/10.1016/j.ijrobp.2004.05.051
70. Nesbit ME, Gehan EA, Burgert EO, Vietti TJ, Cangir A, Tefft M, Evans R, Thomas P, Askin FB, Kissane JM (1990) Multimodal therapy for the management of primary, nonmetastatic Ewing's sarcoma of bone: a long-term follow-up of the First Intergroup study. J Clin Oncol 8:1664–1674. https://doi.org/10.1200/jco.1990.8.10.1664
71. Foulon S, Brennan B, Gaspar N et al (2016) Can postoperative radiotherapy be omitted in localised standard-risk Ewing sarcoma? An observational study of the Euro-EWING group. Eur J Cancer 61:128–136. https://doi.org/10.1016/j.ejca.2016.03.075
72. Rombi B, DeLaney TF, MacDonald SM, Huang MS, Ebb DH, Liebsch NJ, Raskin KA, Yeap BY, Marcus KJ, Tarbell NJ, Yock TI (2012) Proton radiotherapy for pediatric Ewing's sarcoma: initial clinical outcomes. Int J Radiat Oncol Biol Phys 82:1142–1148. https://doi.org/10.1016/j.ijrobp.2011.03.038
73. Gokaslan ZL, Zadnik PL, Sciubba DM et al (2016) Mobile spine chordoma: results of 166 patients from the AOSpine Knowledge Forum Tumor database. J Neurosurg Spine 24:644–651. https://doi.org/10.3171/2015.7.SPINE15201
74. Zhou J, Yang B, Wang X, Jing Z (2018) Comparison of the effectiveness of radiotherapy with photons and particles for chordoma after surgery: a meta-analysis. World Neurosurg 117:46–53. https://doi.org/10.1016/j.wneu.2018.05.209
75. Rutz HP, Weber DC, Sugahara S, Timmermann B, Lomax AJ, Bolsi A, Pedroni E, Coray A, Jermann M, Goitein G (2007) Extracranial chordoma: outcome in patients treated with function-preserving surgery followed by spot-scanning proton beam irradiation. Int J Radiat Oncol Biol Phys 67:512–520. https://doi.org/10.1016/j.ijrobp.2006.08.052
76. Carpentier A, Polivka M, Blanquet A, Lot G, George B (2002) Suboccipital and cervical chordomas: the value of aggressive treatment at first presentation of the disease. J Neurosurg 97:1070–1077. https://doi.org/10.3171/jns.2002.97.5.1070
77. Kabolizadeh P, Chen YL, Liebsch N, Hornicek FJ, Schwab JH, Choy E, Rosenthal DI, Niemierko A, DeLaney TF (2017) Updated outcome and analysis of tumor response in mobile spine and sacral chordoma treated with definitive high-dose photon/proton radiation therapy. Int J Radiat Oncol Biol Phys 97:254–262. https://doi.org/10.1016/j.ijrobp.2016.10.006
78. Boriani S, Amendola L, Bandiera S, Simoes CE, Alberghini M, Di Fiore M, Gasbarrini A (2012) Staging and treatment of osteoblastoma in the mobile spine: a review of 51 cases. Eur Spine J 21:2003–2010. https://doi.org/10.1007/s00586-012-2395-8
79. Cao S, Chen K, Jiang L, Wei F, Liu X, Liu Z (2022) Intralesional marginal resection for osteoblastoma in the mobile spine: experience from a single center. Front Surg 9:838235. https://doi.org/10.3389/fsurg.2022.838235
80. Versteeg AL, Dea N, Boriani S et al (2017) Surgical management of spinal osteoblastomas. J Neurosurg Spine 27:321–327. https://doi.org/10.3171/2017.1.spine16788
81. Ozsahin M, Tsang RW, Poortmans P et al (2006) Outcomes and patterns of failure in solitary plasmacytoma: a multicenter Rare Cancer Network study of 258 patients. Int J Radiat Oncol Biol Phys 64:210–217. https://doi.org/10.1016/j.ijrobp.2005.06.039
82. Reed V, Shah J, Medeiros LJ, Ha CS, Mazloom A, Weber DM, Arzu IY, Orlowski RZ, Thomas SK, Shihadeh F, Alexanian R, Dabaja BS (2011) Solitary plasmacytomas: outcome and prognostic factors after definitive radiation therapy. Cancer 117:4468–4474. https://doi.org/10.1002/cncr.26031
83. Frassica DA, Frassica FJ, Schray MF, Sim FH, Kyle RA (1989) Solitary plasmacytoma of bone: mayo clinic experience. Int J Radiat Oncol Biol Phys 16:43–48. https://doi.org/10.1016/0360-3016(89)90008-4
84. Gouin F, Rochwerger AR, Di Marco A, Rosset P, Bonnevialle P, Fiorenza F, Anract P (2014) Adjuvant treatment with zoledronic acid after extensive curettage for giant cell tumours of bone. Eur J Cancer 50:2425–2431. https://doi.org/10.1016/j.ejca.2014.06.003
85. Chawla S, Blay JY, Rutkowski P et al (2019) Denosumab in patients with giant-cell tumour of bone: a multicentre, open-label, phase 2 study. Lancet Oncol 20:1719–1729. https://doi.org/10.1016/s1470-2045(19)30663-1
86. Rutkowski P, Gaston L, Borkowska A et al (2018) Denosumab treatment of inoperable or locally advanced giant cell tumor of bone—multicenter analysis outside clinical trial. Eur J Surg Oncol 44:1384–1390. https://doi.org/10.1016/j.ejso.2018.03.020
87. Rutkowski P, Ferrari S, Grimer RJ, Stalley PD, Dijkstra SPD, Pienkowski A, Vaz G, Wunder JS, Seeger LL, Feng A, Roberts ZJ, Bach BA (2015) Surgical downstaging in an open-label phase II trial of denosumab in patients with giant cell tumor of bone. Ann Surg Oncol 22:2860–2868. https://doi.org/10.1245/s10434-015-4634-9
88. Müther M, Schwake M, Suero Molina E, Schroeteler J, Stummer W, Klingenhöfer M, Ewelt C (2021) Multiprofessional management of giant cell tumors in the cervical spine: a systematic

review. World Neurosurg 151:53–60. https://doi.org/10.1016/j.wneu.2021.04.006
89. Gupta AK, Phukan P, Bodhey N (2021) Percutaneous vertebroplasty for the treatment of symptomatic vertebral hemangioma with long-term follow-up. Interdiscip Neurosurg 23:100968. https://doi.org/10.1016/j.inat.2020.100968
90. Heyd R, Seegenschmiedt MH, Rades D, Winkler C, Eich HT, Bruns F, Gosheger G, Willich N, Micke O (2010) Radiotherapy for symptomatic vertebral hemangiomas: results of a multicenter study and literature review. Int J Radiat Oncol Biol Phys 77:217–225. https://doi.org/10.1016/j.ijrobp.2009.04.055
91. Kato S, Kawahara N, Murakami H, Demura S, Yoshioka K, Okayama T, Fujita T, Tomita K (2010) Surgical management of aggressive vertebral hemangiomas causing spinal cord compression: long-term clinical follow-up of five cases. J Orthop Sci 15:350–356. https://doi.org/10.1007/s00776-010-1483-z
92. Sagoo NS, Haider AS, Chen AL et al (2022) Radiofrequency ablation for spinal osteoid osteoma: a systematic review of safety and treatment outcomes. Surg Oncol 41:101747. https://doi.org/10.1016/j.suronc.2022.101747
93. Izzo A, Zugaro L, Fascetti E, Bruno F, Zoccali C, Arrigoni F (2021) Management of osteoblastoma and giant osteoid osteoma with percutaneous thermoablation techniques. J Clin Med 10:5717. https://doi.org/10.3390/jcm10245717
94. Aiba H, Hayashi K, Inatani H, Satoshi Y, Watanabe N, Sakurai H, Tsuchiya H, Otsuka T (2014) Conservative treatment for patients with osteoid osteoma: a case series. Anticancer Res 34:3721–3725
95. Tsoumakidou G, Thénint MA, Garnon J, Buy X, Steib JP, Gangi A (2016) Percutaneous image-guided laser photocoagulation of spinal osteoid osteoma: a single-institution series. Radiology 278:936–943. https://doi.org/10.1148/radiol.2015150491
96. Meng L, Zhang X, Xu R, Wu B, Zhang X, Wei Y, Li J, Shan H, Xiao Y (2021) A preliminary comparative study of percutaneous CT-guided cryoablation with surgical resection for osteoid osteoma. PeerJ 9:e10724. https://doi.org/10.7717/peerj.10724
97. Yakkanti R, Onyekwelu I, Carreon LY, Dimar JR (2018) Solitary osteochondroma of the spine-a case series: review of solitary osteochondroma with myelopathic symptoms. Glob Spine J 8:323–339. https://doi.org/10.1177/2192568217701096
98. Boriani S, De Iure F, Campanacci L, Gasbarrini A, Bandiera S, Biagini R, Bertoni F, Picci P (2001) Aneurysmal bone cyst of the mobile spine: report on 41 cases. Spine 26:27–35. https://doi.org/10.1097/00007632-200101010-00007
99. Zhao Y, He S, Sun H, Cai X, Gao X, Wang P, Wei H, Xu W, Xiao J (2019) Symptomatic aneurysmal bone cysts of the spine: clinical features, surgical outcomes, and prognostic factors. Eur Spine J 28:1537–1545. https://doi.org/10.1007/s00586-019-05920-7
100. Zileli M, Isik HS, Ogut FE, Is M, Cagli S, Calli C (2013) Aneurysmal bone cysts of the spine. Eur Spine J 22:593–601. https://doi.org/10.1007/s00586-012-2510-x
101. Parker J, Soltani S, Boissiere L, Obeid I, Gille O, Kieser DC (2019) Spinal aneurysmal bone cysts (ABCs): optimal management. Orthop Res Rev 11:159–166. https://doi.org/10.2147/ORR.S211834
102. Elsayad K, Kriz J, Seegenschmiedt H, Imhoff D, Heyd R, Eich HT, Micke O (2016) Radiotherapy for aneurysmal bone cysts: a rare indication. Strahlenther Onkol 193:332–340. https://doi.org/10.1007/s00066-016-1085-6
103. Charest-Morin R, Fisher CG, Varga PP et al (2017) En bloc resection versus intralesional surgery in the treatment of giant cell tumor of the spine. Spine 42:1383–1390. https://doi.org/10.1097/brs.0000000000002094
104. Luksanapruksa P, Buchowski JM, Singhatanadgige W, Rose PC, Bumpass DB (2016) Management of spinal giant cell tumors. Spine J 16:259–269. https://doi.org/10.1016/j.spinee.2015.10.045
105. Boriani S, Cecchinato R, Cuzzocrea F, Bandiera S, Gambarotti M, Gasbarrini A (2019) Denosumab in the treatment of giant cell tumor of the spine. Preliminary report, review of the literature and protocol proposal. Eur Spine J 29:257–271. https://doi.org/10.1007/s00586-019-05997-0
106. Stanton RP, Ippolito E, Springfield D, Lindaman L, Wientroub S, Leet A (2012) The surgical management of fibrous dysplasia of bone. Orphanet J Rare Dis 7(Suppl 1):S1. https://doi.org/10.1186/1750-1172-7-S1-S1
107. Hassan BW, Moon BJ, Kim YJ, Kim SD, Choi KY, Lee JK (2016) Langerhans cell histiocytosis in the adult lumbar spine: case report. Springerplus 5:1398. https://doi.org/10.1186/s40064-016-3006-7
108. Chen L, Chen Z, Wang Y (2018) Langerhans cell histiocytosis at L5 vertebra treated with en bloc vertebral resection: a case report. World J Surg Oncol 16:96. https://doi.org/10.1186/s12957-018-1399-1
109. Kim SD, Moon BJ, Choi KY, Lee JK (2017) Primary Langerhans cell histiocytosis (LCH) in the adult cervical spine: a case report and review of the literature. Interdiscip Neurosurg 7:56–58. https://doi.org/10.1016/j.inat.2016.11.008
110. Conti A, Acker G, Kluge A, Loebel F, Kreimeier A, Budach V, Vajkoczy P, Ghetti I, Germano AF, Senger C (2019) Decision making in patients with metastatic spine. The role of minimally invasive treatment modalities. Front Oncol 9:915. https://doi.org/10.3389/fonc.2019.00915
111. Ahmed AK, Goodwin CR, Heravi A, Kim R, Abu-Bonsrah N, Sankey E, Kerekes D, Ramos RDLG, Schwab J, Sciubba DM (2018) Predicting survival for metastatic spine disease: a comparison of nine scoring systems. Spine J 18:1804–1814. https://doi.org/10.1016/j.spinee.2018.03.011
112. Pennington Z, Ahmed AK, Westbroek EM, Cottrill E, Lubelski D, Goodwin ML, Sciubba DM (2019) SINS score and stability: evaluating the need for stabilization within the uncertain category. World Neurosurg 128:e1034–e1047. https://doi.org/10.1016/j.wneu.2019.05.067
113. Laufer I, Rubin DG, Lis E, Cox BW, Stubblefield MD, Yamada Y, Bilsky MH (2013) The NOMS framework: approach to the treatment of spinal metastatic tumors. Oncologist 18:744–751. https://doi.org/10.1634/theoncologist.2012-0293
114. Takagi T, Katagiri H, Kim Y et al (2015) Skeletal metastasis of unknown primary origin at the initial visit: a retrospective analysis of 286 cases. PLoS One 10:e0129428. https://doi.org/10.1371/journal.pone.0129428
115. Vecht CJ, Haaxma-Reiche H, van Putten WLJ, Visser M, Vries EP, Twijnstra A (1989) Initial bolus of conventional versus high-dose dexamethasone in metastatic spinal cord compression. Neurology 39:1255–1257. https://doi.org/10.1212/wnl.39.9.1255
116. Skeoch GD, Tobin MK, Khan S, Linninger AA, Mehta AI (2017) Corticosteroid treatment for metastatic spinal cord compression: a review. Glob Spine J 7:272–279. https://doi.org/10.1177/2192568217699189
117. Weber M, Kumar A (2015) Spinal metastases and steroid treatment: a systematic review. Glob Spine J 5:s-003-51554325-s−1550035-1554325. https://doi.org/10.1055/s-0035-1554325
118. Orenday-Barraza JM, Cavagnaro MJ, Avila MJ, Strouse IM, Dowell A, Kisana H, Khan N, Ravinsky R, Baaj AA (2022) 10-year trends in the surgical management of patients with spinal metastases: a scoping review. World Neurosurg 157:170-186.e3. https://doi.org/10.1016/j.wneu.2021.10.086
119. Spiessberger A, Arvind V, Gruter B, Cho SK (2020) Thoracolumbar corpectomy/spondylectomy for spinal metastasis: a pooled analysis comparing the outcome of seven different

surgical approaches. Eur Spine J 29:248–256. https://doi.org/10.1007/s00586-019-06179-8
120. Pennington Z, Ahmed AK, Molina CA, Ehresman J, Laufer I, Sciubba DM (2018) Minimally invasive versus conventional spine surgery for vertebral metastases: a systematic review of the evidence. Ann Transl Med 6:103. https://doi.org/10.21037/atm.2018.01.28
121. Germano IM, Carai A, Pawha P, Blacksburg S, Lo YC, Green S (2016) Clinical outcome of vertebral compression fracture after single fraction spine radiosurgery for spinal metastases. Clin Exp Metastasis 33:143–149. https://doi.org/10.1007/s10585-015-9764-8
122. Kato S, Demura S, Shinmura K, Yokogawa N, Shimizu T, Murakami H, Kawahara N, Tomita K, Tsuchiya H (2021) Surgical metastasectomy in the spine: a review article. Oncologist 26:e1833–e1843. https://doi.org/10.1002/onco.13840
123. Domenicucci M, Nigro L, Delfini R (2018) Total en-bloc spondylectomy through a posterior approach: technique and surgical outcome in thoracic metastases. Acta Neurochir 160:1373–1376. https://doi.org/10.1007/s00701-018-3572-2
124. Tomita K, Kawahara N, Murakami H, Demura S (2006) Total en bloc spondylectomy for spinal tumors: improvement of the technique and its associated basic background. J Orthop Sci 11:3–12. https://doi.org/10.1007/s00776-005-0964-y
125. Nas ÖF, İnecikli MF, Hacıkurt K, Büyükkaya R, Özkaya G, Özkalemkaş F, Ali R, Erdoğan C, Hakyemez B (2016) Effectiveness of percutaneous vertebroplasty in patients with multiple myeloma having vertebral pain. Diagn Interv Radiol 22:263–268. https://doi.org/10.5152/dir.2016.15201
126. Papanastassiou ID, Vrionis FD (2016) Is early vertebroplasty/kyphoplasty justified in multiple myeloma given the rapid vertebral fracture progression? Spine J 16:833–834. https://doi.org/10.1016/j.spinee.2015.12.083
127. Fan Y, Zhou X, Wang H, Jiang P, Cai S, Zhang J, Liu Y (2016) The timing of surgical intervention in the treatment of complete motor paralysis in patients with spinal metastasis. Eur Spine J 25:4060–4066. https://doi.org/10.1007/s00586-016-4406-7
128. Laufer I, Zuckerman SL, Bird JE, Bilsky MH, Lazáry Á, Quraishi NA, Fehlings MG, Sciubba DM, Shin JH, Mesfin A, Sahgal A, Fisher CG (2016) Predicting neurologic recovery after surgery in patients with deficits secondary to MESCC: systematic review. Spine 41(Suppl 20):S224–S230. https://doi.org/10.1097/BRS.0000000000001827
129. Boriani S, Tedesco G, Ming L, Ghermandi R, Amichetti M, Fossati P, Krengli M, Mavilla L, Gasbarrini A (2017) Carbon-fiber-reinforced PEEK fixation system in the treatment of spine tumors: a preliminary report. Eur Spine J 27:874–881. https://doi.org/10.1007/s00586-017-5258-5
130. Krätzig T, Mende KC, Mohme M, Kniep H, Dreimann M, Stangenberg M, Westphal M, Gauer T, Eicker SO (2020) Carbon fiber–reinforced PEEK versus titanium implants: an in vitro comparison of susceptibility artifacts in CT and MR imaging. Neurosurg Rev 44:2163–2170. https://doi.org/10.1007/s10143-020-01384-2
131. Trungu S, Ricciardi L, Forcato S, Scollato A, Minniti G, Miscusi M, Raco A (2021) Anterior corpectomy and plating with carbon-PEEK instrumentation for cervical spinal metastases: clinical and radiological outcomes. J Clin Med 10:5910. https://doi.org/10.3390/jcm10245910
132. Berjano P, Baroncini A, Cecchinato R, Langella F, Boriani S (2021) En-bloc resection of a chordoma in L3 by a combined open posterior and less invasive retroperitoneal approach: technical description and case report. Arch Orthop Trauma Surg. https://doi.org/10.1007/s00402-021-04177-4
133. Murthy NK, Wolinsky JP (2021) Utility of carbon fiber instrumentation in spinal oncology. Heliyon 7:e07766. https://doi.org/10.1016/j.heliyon.2021.e07766
134. Wagner A, Haag E, Joerger A-K, Jost P, Combs SE, Wostrack M, Gempt J, Meyer B (2021) Comprehensive surgical treatment strategy for spinal metastases. Sci Rep 11:7988. https://doi.org/10.1038/s41598-021-87121-1
135. Brookes MJ, Chan CD, Baljer B, Wimalagunaratna S, Crowley TP, Ragbir M, Irwin A, Gamie Z, Beckingsale T, Ghosh KM, Rankin KS (2021) Surgical advances in osteosarcoma. Cancers 13:388. https://doi.org/10.3390/cancers13030388
136. Park SJ, Lee KH, Lee CS, Jung JY, Park JH, Kim GL, Kim KT (2020) Instrumented surgical treatment for metastatic spinal tumors: is fusion necessary? J Neurosurg Spine 32:456–464. https://doi.org/10.3171/2019.8.spine19583
137. Hong CG, Cho JH, Suh DC, Hwang CJ, Lee DH, Lee CS (2017) Preoperative embolization in patients with metastatic spinal cord compression: mandatory or optional? World J Surg Oncol 15:45. https://doi.org/10.1186/s12957-017-1118-3
138. Ryu S, Deshmukh S, Timmerman RD et al (2019) Radiosurgery compared to external beam radiotherapy for localized spine metastasis: phase III results of NRG oncology/RTOG 0631. Int J Radiat Oncol Biol Phys 105:S2–S3. https://doi.org/10.1016/j.ijrobp.2019.06.382
139. Sahgal A, Myrehaug SD, Siva S et al (2020) CCTG SC.24/TROG 17.06: a randomized phase II/III study comparing 24Gy in 2 stereotactic body radiotherapy (SBRT) fractions versus 20Gy in 5 conventional palliative radiotherapy (CRT) fractions for patients with painful spinal metastases. Int J Radiat Oncol Biol Phys 108:1397–1398. https://doi.org/10.1016/j.ijrobp.2020.09.019
140. Gerszten PC, Burton SA, Ozhasoglu C, Welch WC (2007) Radiosurgery for spinal metastases: clinical experience in 500 cases from a single institution. Spine 32:193–199. https://doi.org/10.1097/01.brs.0000251863.76595.a2
141. Tao R, Bishop AJ, Brownlee Z et al (2016) Stereotactic body radiation therapy for spinal metastases in the postoperative setting: a secondary analysis of mature phase 1–2 trials. Int J Radiat Oncol Biol Phys 95:1405–1413. https://doi.org/10.1016/j.ijrobp.2016.03.022
142. Ryu S, Pugh SL, Gerszten PC, Yin F-F, Timmerman RD, Hitchcock YJ, Movsas B, Kanner AA, Berk LB, Followill DS, Kachnic LA (2014) RTOG 0631 phase 2/3 study of image guided stereotactic radiosurgery for localized (1–3) spine metastases: phase 2 results. Pract Radiat Oncol 4:76–81. https://doi.org/10.1016/j.prro.2013.05.001
143. Miller JA, Balagamwala EH, Berriochoa CA, Angelov L, Suh JH, Benzel EC, Mohammadi AM, Emch T, Magnelli A, Godley A, Qi P, Chao ST (2017) The impact of decompression with instrumentation on local failure following spine stereotactic radiosurgery. J Neurosurg Spine 27:436–443. https://doi.org/10.3171/2017.3.spine161015
144. Husain ZA, Sahgal A, De Salles A et al (2017) Stereotactic body radiotherapy for de novo spinal metastases: systematic review. J Neurosurg Spine 27:295–302. https://doi.org/10.3171/2017.1.spine16684
145. Palma DA, Olson R, Harrow S et al (2020) Stereotactic ablative radiotherapy for the comprehensive treatment of oligometastatic cancers: long-term results of the SABR-COMET phase II randomized trial. J Clin Oncol 38:2830–2838. https://doi.org/10.1200/JCO.20.00818
146. Myrehaug S, Sahgal A, Hayashi M, Levivier M, Ma L, Martinez R, Paddick I, Régis J, Ryu S, Slotman B, De Salles A (2017) Reirradiation spine stereotactic body radiation therapy for spinal

metastases: systematic review. J Neurosurg Spine 27:428–435. https://doi.org/10.3171/2017.2.spine16976
147. Spratt DE, Beeler WH, de Moraes FY et al (2017) An integrated multidisciplinary algorithm for the management of spinal metastases: an international spine oncology consortium report. Lancet Oncol 18:e720–e730. https://doi.org/10.1016/s1470-2045(17)30612-5
148. Thirion PG, Dunne MT, Kelly PJ et al (2020) Non-inferiority randomised phase 3 trial comparing two radiation schedules (single vs. five fractions) in malignant spinal cord compression. Br J Cancer 122:1315–1323. https://doi.org/10.1038/s41416-020-0768-z
149. Patchell RA, Tibbs PA, Regine WF, Payne R, Saris S, Kryscio RJ, Mohiuddin M, Young B (2005) Direct decompressive surgical resection in the treatment of spinal cord compression caused by metastatic cancer: a randomised trial. Lancet 366:643–648. https://doi.org/10.1016/s0140-6736(05)66954-1
150. George R, Jeba J, Ramkumar G, Chacko AG, Tharyan P (2015) Interventions for the treatment of metastatic extradural spinal cord compression in adults. Cochrane Database Syst Rev. https://doi.org/10.1002/14651858.CD006716.pub3
151. Di Perna G, Cofano F, Mantovani C, Badellino S, Marengo N, Ajello M, Comite LM, Palmieri G, Tartara F, Zenga F, Ricardi U, Garbossa D (2020) Separation surgery for metastatic epidural spinal cord compression: a qualitative review. J Bone Oncol 25:100320. https://doi.org/10.1016/j.jbo.2020.100320
152. Barzilai O, Amato MK, McLaughlin L, Reiner AS, Ogilvie SQ, Lis E, Yamada Y, Bilsky MH, Laufer I (2018) Hybrid surgery–radiosurgery therapy for metastatic epidural spinal cord compression: a prospective evaluation using patient-reported outcomes. Neurooncol Pract 5:104–113. https://doi.org/10.1093/nop/npx017
153. Itshayek E, Cohen JE, Yamada Y, Gokaslan Z, Polly DW, Rhines LD, Schmidt MH, Varga PP, Mahgarefteh S, Fraifeld S, Gerszten PC, Fisher CG (2014) Timing of stereotactic radiosurgery and surgery and wound healing in patients with spinal tumors: a systematic review and expert opinions. Neurol Res 36:510–523. https://doi.org/10.1179/1743132814y.0000000380
154. Azad TD, Varshneya K, Herrick DB, Pendharkar AV, Ho AL, Stienen M, Zygourakis C, Bagshaw HP, Veeravagu A, Ratliff JK, Desai A (2021) Timing of adjuvant radiation therapy and risk of wound-related complications among patients with spinal metastatic disease. Glob Spine J 11:44–49. https://doi.org/10.1177/2192568219889363
155. Degen JW, Gagnon GJ, Voyadzis J-M, McRae DA, Lunsden M, Dieterich S, Molzahn I, Henderson FC (2005) CyberKnife stereotactic radiosurgical treatment of spinal tumors for pain control and quality of life. J Neurosurg Spine 2:540–549. https://doi.org/10.3171/spi.2005.2.5.0540
156. Roesch J, Cho JBC, Fahim DK et al (2017) Risk for surgical complications after previous stereotactic body radiotherapy of the spine. Radiat Oncol 12:153. https://doi.org/10.1186/s13014-017-0887-8
157. Versteeg AL, van der Velden JM, Hes J, Eppinga W, Kasperts N, Verkooijen HM, Oner FC, Seravalli E, Verlaan JJ (2018) Stereotactic radiotherapy followed by surgical stabilization within 24 h for unstable spinal metastases; a stage I/IIa study according to the IDEAL framework. Front Oncol 8:626. https://doi.org/10.3389/fonc.2018.00626
158. Lin PC, Hsu FM, Chen YH, Xiao F (2018) Neoadjuvant stereotactic body radiation therapy for spine metastases. J Spine Neurosurg 7(2). https://doi.org/10.4172/2325-9701.1000298
159. Kumar N, Madhu S, Bohra H, Pandita N, Wang SSY, Lopez KG, Tan JH, Vellayappan BA (2020) Is there an optimal timing between radiotherapy and surgery to reduce wound complications in metastatic spine disease? A systematic review. Eur Spine J 29:3080–3115. https://doi.org/10.1007/s00586-020-06478-5
160. Lee RS, Batke J, Weir L, Dea N, Fisher CG (2018) Timing of surgery and radiotherapy in the management of metastatic spine disease: expert opinion. J Spine Surg 4:368–373. https://doi.org/10.21037/jss.2018.05.05
161. Wang X, Yang JN, Li X, Tailor R, Vassilliev O, Brown P, Rhines L, Chang E (2013) Effect of spine hardware on small spinal stereotactic radiosurgery dosimetry. Phys Med Biol 58:6733–6747. https://doi.org/10.1088/0031-9155/58/19/6733



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