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ORIGINAL ARTICLE

Composite PEEK/carbon fiber rods in the treatment for bone tumors of the cervical spine: a case series

Stefano Boriani[1] · Valerio Pipola[2] · Riccardo Cecchinato[1] · Riccardo Ghermandi[2] · Giuseppe Tedesco[2] · Maria Rosaria Fiore[3] · Francesco Dionisi[4] · Alessandro Gasbarrini[2]

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Abstract

Introduction Radiotherapy (RT) is frequently applied as an adjuvant therapy during spinal tumors treatment. Metallic implants can interfere with RT planning and execution, as it is known that metallic implants produce a backscattering effect that can limit RT accuracy and their presence can be associated with unwanted dose increase. PEEK/carbon fiber implants are designed to reduce these problems but their application in the cervical spine is limited, due to the reduced number and types of implants, the screw dimensions and the absence of lateral mass screws. We propose a hybrid system made of carbon rods and screws coupled with subliminal polyester bands with titanium clamps. We designed this hybrid construct to enclose the cervical region in the area of instrumentation without limiting the application of postoperative radiotherapy.

Materials and methods Six patients in which the hybrid hardware was implanted were retrospectively examined. Data on demographics, intraoperative and postoperative events, tumor details and staging and cervical alignment were collected pre- and postoperatively.

Results No intraoperative complications occurred. En bloc resection was performed in two patients, while the remaining four received an intralesional resection. Three out of six patients received postoperative RT, without any alteration in its planning and administration.

Discussion and conclusions Hybrid implants made of composite PEEK/carbon fiber screws and rods and sublaminar bands are a helpful solution for spinal reconstruction in the cervical and cervico-thoracic regions after spine tumor surgery. The implants do not produce artifacts at postoperative images, easing the planning and execution of postoperative radiotherapy.

Keywords Spine tumor · Carbon fiber implants · Radiotherapy · Spinal reconstruction

Introduction

Primary tumors of the spine are rare conditions and account for around 5–10% of all tumors in the spine [1–3] being a challenge for both clinicians and patients due to the difficulties involved in diagnosis and treatment [4]. Spinal tumors present with nonspecific and variable symptoms, the most common of which is pain. Other symptoms include weakness, paresthesia and radicular pain [5]. The secondary symptoms of tumors involving cervical spine (such as respiratory failure, paraplegia and quadriplegia) generally tend to be more serious than those associated with tumors of the thoracic and lumbar spine [6]. For determining the best approach and the extent of surgical resection required, spinal tumors are classified using the modified Enneking staging system and the Weinstein–Boriani–Biagini (WBB) classification system [3, 7]. The treatment objectives of metastatic spinal tumors are multiple and generally include restoration and maintenance of neurological function and spinal stability, local tumor control, early detection and treatment of recurrences, improvement in QoL [8]. Due to the unique anatomical properties of the spine, the stability of the spine after tumor resection should be ensured using surgical implants such as pedicle screws and rods [9, 10]. Generally, posterior pedicle fixation is performed to achieve

✉ Riccardo Cecchinato
riccardo.cecchinato@grupposandonato.it

[1] GSpine4, IRCCS Istituto Ortopedico Galeazzi, Milan, Italy

[2] IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy

[3] Radiotherapy Unit, National Center of Oncological Hadrontherapy (CNAO), Pavia, Italy

[4] Centro di Protonterapia, Trento, Italy

spinal stability, and additional anterior fixation is performed if the anterior column support is deemed inadequate [11]. To comprehensively achieve these treatment objectives, adjuvant radiotherapy is often employed in addition to surgical resection of the tumor. Conversely, the treatment for primary tumors is based on en bloc resections [7, 9], targeted to the tumor excision according to the oncological principles. In the case of accidental contamination of the margins or in the case of intentional transgression to oncologic principles, adjuvant radiotherapy, mostly by accelerated particles, is required for local control. The advent of stereotactic body radiotherapy for spine allowed the accurate delivery of charged particles to the tumor site [12].

The conventional spine implants that are used for fixation are made of metals such as titanium and have been found to alter the dose of adjuvant radiotherapy due to backscattering and inadverted dose increase. As a result, there is not only a compromise in the therapeutic effect, but also an unwanted and intolerable irradiation of surrounding healthy tissues [13–15]. Metallic implants also interfere with postsurgical follow-up imaging [16]. As a solution to these problems, radiolucent implants made from polyetheretherketone reinforced with carbon fiber (PEEK/CF) are now available. These have been proven to facilitate adjuvant radiotherapy as well as follow-up imaging, while being equally effective when compared to titanium implants [14, 17–19]. However, posterior fixation of the cervical spine can represent a problem, as the smaller 5.5 mm composite PEEK/CF screws are only suitable for posterior fixation of the higher thoracic spine but not of the cervical spine. The use of titanium connectors in the cervical spine may interfere with radiotherapy and follow-up imaging as described above. To solve these problems, we developed a technique in which the composite PEEK/CF rods were connected to the laminae by a polyester (polyethylene terephthalate) band (Jazz™ by Implanet®/ Nile™ by Stryker-K2M®) using titanium connectors placed outside the possible radiotherapy field.

In this article, we describe a case series of six patients with cervical or high-thoracic spine tumors operated at our center, in which posterior fixation of the cervical spine was performed using this construct. The purpose is to demonstrate its stability at short and middle term and the feasibility of radiotherapy with this type of implant.

Case series

We used this construct in the posterior fixation of cervical spine as a part of surgical management of six patients with cervical or high-thoracic tumors treated between February and November 2017 by the same surgical team. We obtained the institutional ethics committee approval for the usage of this construct in eligible patients.

Baseline parameters, tumor details and staging, eventual previous treatments and surgical procedures are summarized in Table 1. As per the American Spinal Injury Association (ASIA) scale, only one out of the six patients had grade D impairment; the remaining five patients had normal motor and sensory functions. En bloc resection was adopted in two patients with grade IIB malignant tumors, while intralesional resection was performed in four patients. All the patients underwent posterior reconstruction using two composite PEEK/CF rods and polyester clamps, whereas thoracic composite PEEK/CF screws were used in two patients in whom the tumor involved both thoracic and cervical vertebrae. Three of the six patients received adjuvant radiotherapy, and the implants did not alter the administration of the radiotherapy. The radiotherapists involved in the procedure observed that there were no scattering effects, and they were able to administer the highest doses on tumor with no effects on surrounding structures. Furthermore, they could obtain excellent imaging definition close to the implant. Local recurrence was observed in two patients; the first patient had a stage IIB malignant epithelioid sclerosing fibrosarcoma treated with en bloc resection, and the second had a stage S3 benign aggressive giant cell tumor treated with intralesional excision. Both were promptly treated, with the first patient receiving radiotherapy, and the second receiving denosumab.

The alignment of cervical sagittal vertical axis (SVA) was measured before and after surgery and at follow-up to evaluate if the implant improves or worsens the spinal alignment, and if the SVA is maintained or deteriorated at follow-up. (Table 1) Cervical SVA can be defined regionally using the distance between a plumb line dropped from the centroid of C-2 (or dens) and the posterosuperior aspect of C-7 (C2–7 SVA). The normal cervical SVA value in asymptomatic adults at C7 has been described as 15.6 ± 11.2 mm [20].

Three of the six cases deserve a detailed description, because of their unique features.

Patient 1 was a 42-year-old male, whose CT scan demonstrated a huge soft tissue mass expanding right from C7 body, which also involved the vertebral artery and vertebral foramen. The tumor was infiltrating the bone, and the limits with adjacent tissues were unclear. Histological examination of CT-guided trocar biopsy sample brought to the diagnosis of epithelioid sclerosing fibrosarcoma with Enneking Stage IIB tumor.

Type 3a En bloc resection [21] was performed by anterior and posterior approach. The right-half vertebra was resected together with ligaments and muscles. Posterior C4–T3 fixation was achieved by two composite PEEK/CF rods, coupled with sublaminar bands placed proximally at C4 and C5 and distally at T2 and T3. Sublaminar bands were placed outside the expected field of radiation. Surgery was uneventful, and no anterior reconstruction was performed at the

Table 1 Summary of baseline demographics, tumor stage, tumor location, performed procedure, adjuvant treatments and cervical alignment of the patients

Pt. No	1	2	3	4	5	6
Age	42 years	65 years	45 years	49 years	45 years	17 years
Gender	Male	Male	Female	Female	Female	Male
Diagnosis	Epithelioid sclerosing fibrosarcoma	Giant cell tumor	Chordoma	Giant cell tumor	Meningioma	Ewing's sarcoma
Tumor location	C7	C3–C4–C5	C4	C6–C7	C7–T1	T1
Enneking Stage	IIB	S3	IB	S3	IB	IIB
WBB Staging	7–12; A–D, F	4–9; A–C	3–8; B–C	1–8; A–D	10–2; C–D	4–9; BC
Maximum Follow-up (months)	37	37	30	34	24	27
ASIA scale before surgery	E	D	E	E	E	E
Previous treatment details	No	No	Intralesional excision + PEEK cage + titanium plate	Intralesional excision + titanium expandable cage + titanium cage	No	Partial intralesional excision + chemotherapy + radiotherapy
Excision performed	En bloc	Intralesional	Intralesional	Intralesional	Intralesional	En bloc
Posterior reconstruction	PEEK/CF double rods					
PEEK/CF Screws	No	No	No	No	T3, T4	T3, T4
Titanium clamp and sublaminar level	C4, T2	C3, C7	C3, C5	C5, T1	C3, C4	C3, C4
Anterior reconstruction	No anterior reconstruction	Allograft + Carbon-fiber cage	Allograft + Carbon-fiber cage	Allograft + Carbon-fiber cage	No anterior reconstruction	PEEK cage + Carbon-fiber cage
Adjuvant treatments	Proton therapy 68 Gy	No adjuvant treatment	Carbon ion therapy 74 Gy	Denosumab (suspended after 1 year)	Proton therapy (75 Gy)	Chemotherapy
ASIA scale after surgery	D	E	No	E	E	E
Alignment measured at	T2	T1	T1	T2	T3	T3
Alignment before surgery	10.0 mm	3.18 mm	5.79 mm	3.57 mm	2.95 mm	5.56 mm
Alignment After surgery	4.8 mm	4.38 mm	5.01 mm	4.97 mm	4.06 mm	5.52 mm
Alignment at follow-up	11 mm	5.16 mm	4.9 mm	5.47 mm	5.94 mm	5.84 mm
Local recurrence and its treatment	24 months; proton therapy irradiation	5 months; denosumab	No	No	No	No
Status at last follow-up	No evidence of disease	Alive with disease	Continuous disease free	Continuous disease free	No evidence of disease	No evidence of disease

time of the resection. The patient was subjected to proton therapy (68 Gy) after the primary surgery. The patient suffered from a local recurrence 24 months after the surgery, which required re-irradiation. Both the courses of proton therapy were performed without any unexpected event. Six months after the surgery, the patient returned with a kyphotic deformity of the cervical spine, which required a revision surgery. It was noted that there was a loss of sagittal alignment without any breakage or loosening of the rods used for the posterior fixation. The anterior fixation was successfully performed using composite PEEK/CF plating. Thus, sublaminar fixation posteriorly without complete anterior column support was unable to maintain stability of the cervical spine in this patient. During the last follow-up visit after 28 months of surgery, the patient was doing well, and CT scan showed no evidence of disease.

Patient 5 (Fig. 1a–e) was a 45-year-old female with multiple stage IB meningiomas involving C7 to T1. Preoperative CT scan revealed a huge soft tissue tumor compressing cervical spinal cord (Fig. 1a), with a dumbbell-like lesion going through the left foramen of T1 (Fig. 1b). The epidural extension was classified as Bilsky 3 [22].

An intralesional excision with extended laminectomy (C6 to T2) was performed. The composite PEEK/CF construct was placed between C3 and T4, with sublaminar bands in C3–4 and composite PEEK/CF pedicle screws in T3–4.

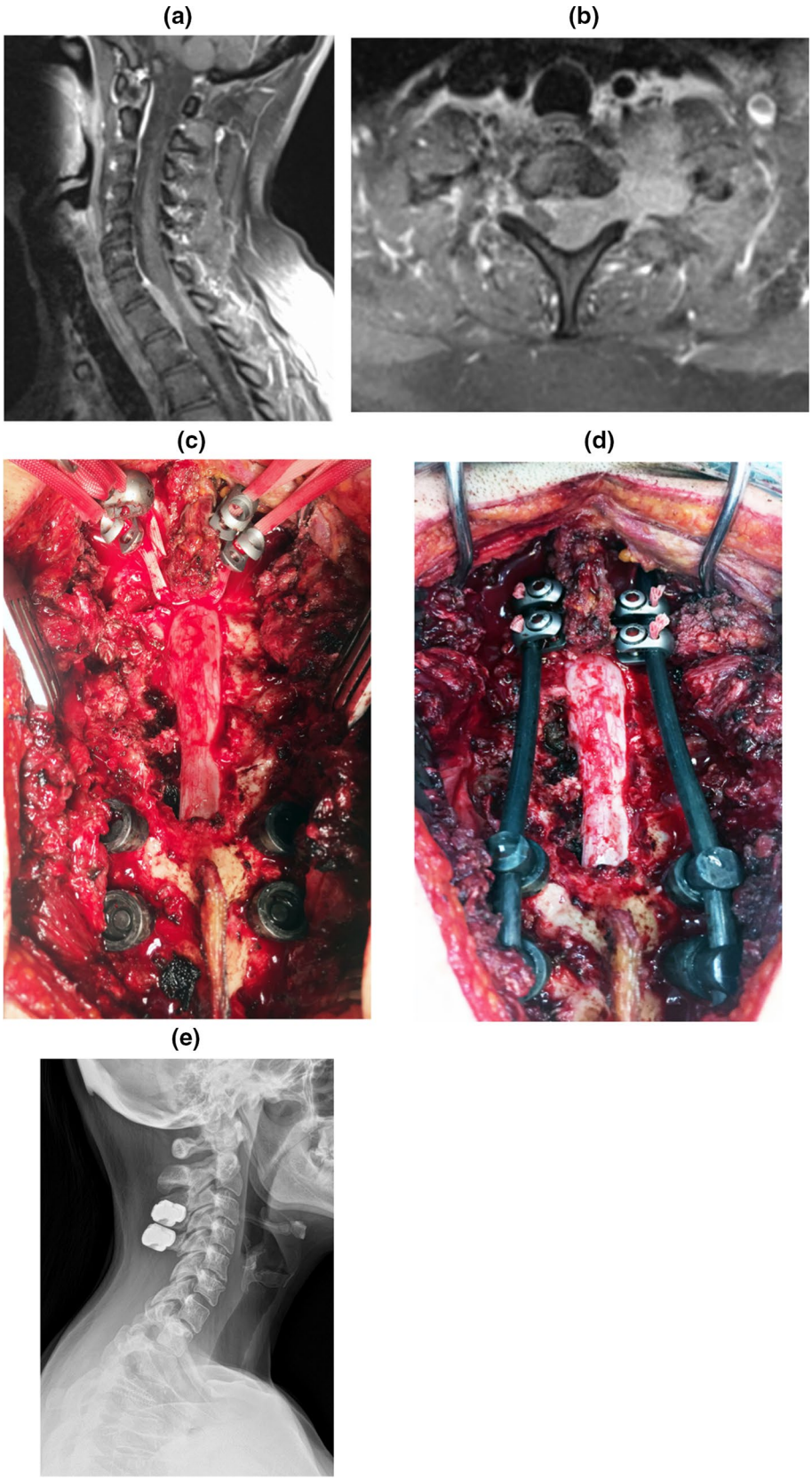

Fig. 1 Patient 5: 45-year-old female with multiple Enneking stage IB meningiomas involving C7-T1. **a** Preoperative CT scan showing spinal cord compression by a huge soft tissue tumor. **b** Preoperative CT scan showing a dumbbell-like soft tissue mass through the left foramen of T1. **c** Intraoperative image after decompression. Sublaminar bends in C3–C4 and composite PEEK/CF pedicle screws in T3 and T4 can be seen. **d** Intraoperative image of the final construct running from C3 to T4. (e) CT scan after 28 months of the surgery

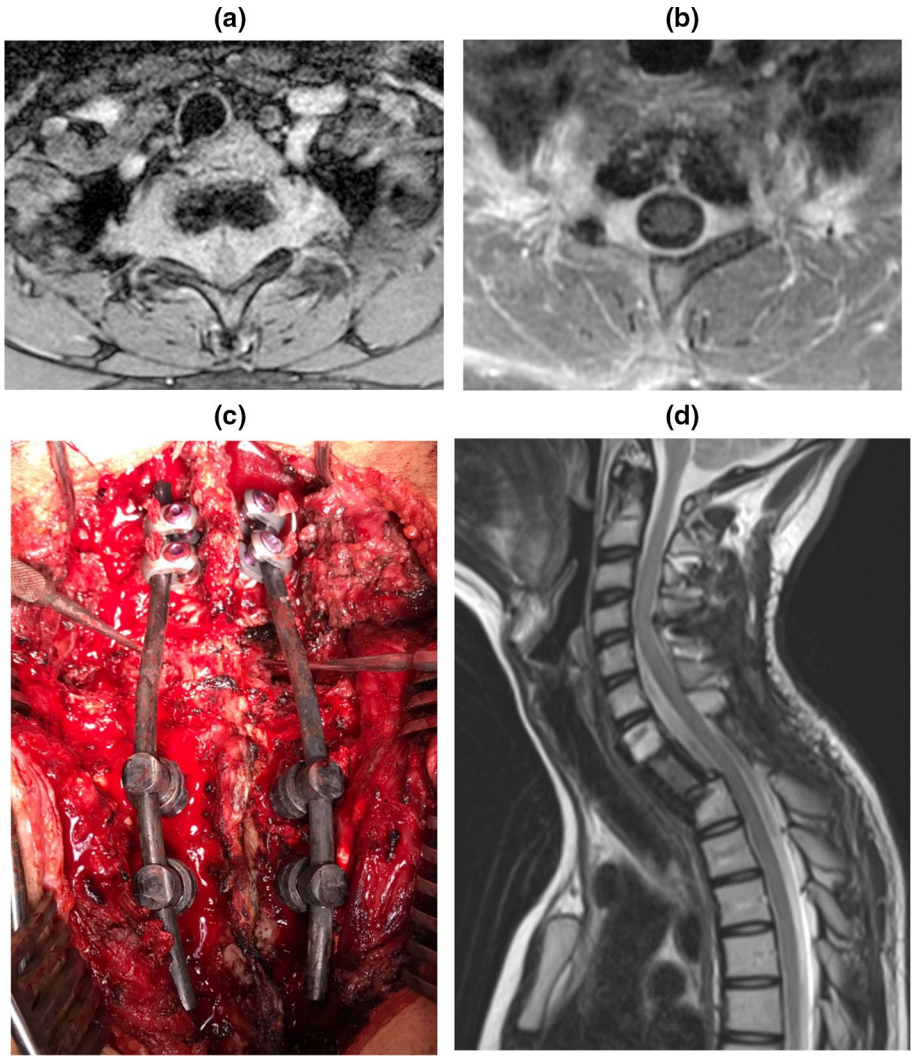

Fig. 2 Patient 6: 17-year-old male with Enneking stage IIB Ewing's sarcoma affecting T1. **a** Preoperative CT scan showing the tumor arising from the vertebral body and expanding in the epidural space and in the anterior soft tissues. **b** Tumor has shrunk after chemotherapy and radiotherapy. **c** Intraoperative image at the end of posterior approach showing composite PEEK/CF rods C4–T4, sublaminar bends in C4 and C5 and composite PEEK/CF pedicle screws in T3 and T4. The dural sac is visible. **d** MRI at 18 months follow-up reveals no displacement of the posterior construct, and no artifacts from the whole construct

(Fig. 1c, d). The titanium clamps were placed outside the possible radiation field. Surgery was uneventful. After the surgery, the patient was subjected to proton therapy (75 Gy), without any complication.

The radiogram after 2 years of follow-up revealed no loss of alignment, and the distal radiolucent composite PEEK/CF screws were hardly visible (Fig. 1e). There were no complaints of neurological symptoms or local recurrence.

Patient 6 (Fig. 2a–d) was a 17-year-old male with recurrent Enneking stage IIB Ewing's sarcoma affecting T1, who had previously undergone partial intralesional excision. On CT scan, the tumor was seen to arise from the vertebral body and expand into the epidural space and anterior soft tissues (Fig. 2a). The patient was subject to chemotherapy and conventional radiotherapy, with tumor mass shrinking (Fig. 2b). Subsequently, en bloc resection with composite PEEK/CF rod placement was scheduled, to facilitate accelerated particle radiotherapy for irradiation, in the case of local recurrence. Type 7 en bloc resection [21] was performed by posterior approach first, followed by anterior approach. After discectomy and resection of the annulus and the posterior longitudinal ligament in C7–T1 and T1–2, the vertebral body was en bloc removed by anterior approach. The composite PEEK/CF rods were positioned in C4–T4 with titanium sublaminar bands in C4–5, polyester clamps at C3–4 and composite PEEK/CF pedicle screws in T3–4. (Figure 2c). On follow-up at 18 months postsurgery, anterior column reconstruction was performed by a PEEK cage filled with autogenous graft. MRI scan revealed no displacement of the posterior construct, and no artifacts were observed (Fig. 2d). This patient received adjuvant chemotherapy, but was not a candidate for adjuvant radiotherapy. At 20-month follow-up, bone skull metastases were observed and treated with surgical excision.

Fig. 3 RT pretreatment planning. It is significant to notice the absence of scattering effect or of any kind of interference given by the implant. Interestingly, the metallic components lay far from the target area in sagittal, coronal and axial planes, avoiding any interference also with radiation beams

Discussion

In this case series, we have explored the usage of PEEK/CF rods in the cervical spine implanted using a novel construct of polyester (polyethylene-terephthalate) clamps (Jazz™ by Implanet®/Nile™ by Stryker-K2M®) and titanium clamps, by ensuring that the titanium connectors were fixed outside the possible radiotherapy field. The individual cases briefed in this report represent somewhat unusual problems that we faced and the strategies we employed on a case-by-case basis. The successful achievement of satisfactory short-term and middle-term longitudinal stability by using the construct demonstrates the validity of the application of this construct in the posterior fixation of the cervical spine after en bloc or intralesional resection of tumors involving cervical and high-thoracic spine.

The use of this construct also was not associated with unwanted interference with postsurgical adjuvant

radiotherapy whenever indicated, nor with artifacts in post-surgical imaging. Three of our six patients received adjuvant radiotherapy with satisfactory comments by radiotherapists. Figure 3 clearly depicts how the presence of CF implants and metallic clamps out of the field of irradiation allows the radiotherapist a precise planning, without scattering effect nor disturbance given by metallic components. To reduce this last problem, we extended one level above and one below the level of fusion with respect to usual planning. The spine was, however, fused following the standard sagittal and coronal criteria for reconstruction [23] in order to provide an adequate alignment on both planes, as we know the cervical spine has a huge ability to compensate and should then be fused in a proper position [24]. To the best of our knowledge, no similar solutions have been reported in the literature to resolve the problem of not using titanium implants for cervical spine tumors with the precaution of placing the titanium implants away from the possible sites of irradiation.

In patient 1, we avoided anterior reconstruction at the time of resection; this was not a wise decision since the patient presented with kyphotic deformity 6 months later, which required revision surgery and anterior fixation. This may suggest, as reported in the literature [25], an inferior biomechanical rigidity of a band-rod construct versus a screw-rod system. We thus recommend to always offer a solid anterior support when using sublaminar bands posteriorly. Some deterioration of the sagittal alignment was found and documented radiographically. In all the cases, it was well tolerated and did not interfere with a satisfactory function. However, it is a limit of the sublaminar fixation and should represent a matter for further studies and improvement

It should be reinforced that primary tumors of the spine are rare, and the surgery for these tumors is technically demanding and relies upon complex multidisciplinary approach. The solution we have tried in this case series appears to be successful for achieving postresection stability in the cervical spine without compromising on adjuvant radiotherapy and postoperative imaging. The findings from this case series of six patients should be further validated by long-term prospective studies involving patients with cervical tumors from a different population, which would also explore the long-term stability of these constructs in addition to the short-term and mid-term stability.

Conclusion

Sublaminar polyester terephthalate bands are a valid solution for extending the use of composite PEEK/CF rods to the cervical spine. For cases where anterior support is poor, anterior fusion is required to provide stability as the longitudinal stability provided by sublaminar wiring/band is suboptimal. Further researches are needed for developing mechanisms to provide stronger connection of the rods to the posterior elements of the spine.

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Compliance with ethical standards

Conflicts of interest None of the authors has any potential conflict of interest.

References

1. Luzzati F, Giusti EM, Scotto GM, Perrucchini G, Cannavò L, Castelnuovo G, Cottini AC (2019) Quality of life, pain, and psychological factors in patients undergoing surgery for primary tumors of the spine. Support Care Cancer 28(3):1385–1393
2. Kerr DL, Dial BL, Lazarides AL, Catanzano AA, Lane WO, Blazer DG 3rd, Brigman BE, Mendoza-Lattes S, Eward WC, Erickson ME (2019) Epidemiologic and survival trends in adult primary bone tumors of the spine. Spine J 19(2):1941–1949
3. Clarke MJ, Mendel E, Vrionis FD (2014) Primary spine tumors: diagnosis and treatment. Cancer Control 21(2):114–123
4. Horick NK, Manful A, Lowery J, Domchek S, Moorman P, Griffin C, Visvanathan K, Isaacs C, Kinney AY, Finkelstein DM (2017) Physical and psychological health in rare cancer survivors. J Cancer Surviv 11(1):158–165
5. Orguc S, Arkun R (2014) Primary tumors of the spine. Semin Musculoskelet Radiol 18(3):280–299
6. Jenis LG, Dunn EJ, An HS (1999) Metastatic disease of the cervical spine: a review. Clin Orthop Relat Res 359:89–103
7. Boriani S, Weinstein JN, Biagini R (1997) Primary bone tumors of the spine. Terminology and surgical staging. Spine (Phila Pa 1976) 22(9):1036–1044
8. Laufer I, Bilsky MH (2019) Advances in the treatment of metastatic spine tumors: the future is not what it used to be. J Neurosurg Spine 30(3):299–307
9. Fisher CG, Keynan O, Boyd MC, Dvorak MF (2005) The surgical management of primary tumors of the spine: initial results of an ongoing prospective cohort study. Spine 30:1899–1908
10. Ponnusamy KE, Iyer S, Gupta G, Khanna AJ (2011) Instrumentation of the osteoporotic spine: biomechanical and clinical considerations. Spine J 11(1):54–63
11. Idowu OE, Adewole OA, Majekodunmi AA (2012) Posterior spinal decompression, stabilization and arthrodesis in Nigerian adults: profile and outcome. Niger Med J 53(1):42–46
12. Barzilai O, Boriani S, Fisher CG, Sahgal A, Verlaan JJ, Gokaslan ZL, Lazary A, Bettegowda C, Rhines LD, Laufer I (2019) Essential concepts for the management of metastatic spine disease: what the surgeon should know and practice. Global Spine J 9(1 Suppl):98S–107S
13. Nevelsky A, Borzov E, Daniel S, Bar-Deroma R (2017) Perturbation effects of the carbon fiber-PEEK screws on radiotherapy dose distribution. J Appl Clin Med Phys 18(2):62–68
14. Laux CJ, Hodel SM, Farshad M, Müller DA (2018) Carbon fibre/polyether ether ketone (CF/PEEK) implants in orthopaedic oncology. World J Surg Oncol 16(1):241

15. Son SH, Kang YN, Ryu MR (2012) The effect of metallic implants on radiation therapy in spinal tumor patients with metallic spinal implants. Med Dosim 37(1):98–107
16. Ringel F, Ryang YM, Kirschke JS, Müller BS, Wilkens JJ, Brodard J, Combs SE, Meyer B (2017) Radiolucent carbon fiber-reinforced pedicle screws for treatment of spinal tumors: advantages for radiation planning and follow-up imaging. World Neurosurg 105:294–301
17. Boriani S, Tedesco G, Ming L, Ghermandi R, Amichetti M, Fossati P, Krengli M, Mavilla L, Gasbarrini A (2018) Carbon-fiber-reinforced PEEK fixation system in the treatment of spine tumors: a preliminary report. Eur Spine J 27(4):874–881
18. Tedesco G, Gasbarrini A, Bandiera S, Ghermandi R, Boriani S (2017) Composite PEEK/Carbon fiber implants can increase the effectiveness of radiotherapy in the management of spine tumors. J Spine Surg 3(3):323–329
19. Brandão RACS, Martins WCDS, Arantes AA Jr, Gusmão SNS, Perrin G, Barrey C (2017) Titanium versus polyetheretherketone implants for vertebral body replacement in the treatment of 77 thoracolumbar spinal fractures. Surg Neurol Int. 8:191
20. Scheer JK, Tang JA, Smith JS, Acosta FL Jr, Protopsaltis TS, Blondel B, Bess S, Shaffrey CI, Deviren V, Lafage V, Schwab F, Ames CP, International Spine Study Group (2013) Cervical spine alignment, sagittal deformity, and clinical implications: a review. J Neurosurg Spine 19(2):141–159
21. Boriani S (2018) En bloc resection in the spine: a procedure of surgical oncology. J Spine Surg 4(3):668–676
22. Bilsky MH, Boland PJ, Panageas KS, Woodruff JM, Brennan MF, Healey JH (2001) Intralesional resection of primary and metastatic sarcoma involving the spine: outcome analysis of 59 patients. Neurosurgery 49(6):1277–1286 **(discussion 1286-7)**
23. Le Huec JC, Thompson W, Mohsinaly Y, Barrey C, Faundez A (2019) Sagittal balance of the spine. Eur Spine J 28(9):1889–1905
24. Cecchinato R, Langella F, Bassani R, Sansone V, Lamartina C, Berjano P (2014) Variations of cervical lordosis and head alignment after pedicle subtraction osteotomy surgery for sagittal imbalance. Eur Spine J 23(6):644–649
25. Bess S, Harris JE, Turner AWL, LaFage V, Smith JS, Shaffrey CI, Schwab FJ, Haid RW Jr (2017) The effect of posterior polyester tethers on the biomechanics of proximal junctional kyphosis: a finite element analysis. J Neurosurg Spine 26(1):125–133