CT-Myelography for High-Dose Irradiation of Spinal and Paraspinal Tumors with Helical Tomotherapy

Revival of an Old Tool

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Background and Purpose: High-dose irradiation or reirradiation of spinal and paraspinal tumors is a challenge particularly in the presence of metal artifacts after surgery. Image-guided advanced intensity-modulated radiotherapy delivers high-dose radiation to the tumor sparing the spinal cord. Precise delineation of the spinal cord is necessary treating para- and intraspinal tumors with a sufficient dose.
Patients and Methods: The use of myelo-CT was evaluated in 23 patients with spinal and paraspinal tumors. All patients had had previous surgery with metal implants in the radiation area. All patients had an indication for high-dose irradiation. Treatment planning was performed using nonenhanced and contrast-enhanced myelo-CT in the same position and immobilization and both CT scans were matched. Treatment was performed by using a tomotherapy treatment unit.
Results: Contouring of the myelon in all slices of the myelo-CT was possible in 20 of 23 patients. All these patients were treated with doses of median 69.4 Gy in 2 Gy/1.8 Gy single doses using daily image guidance. One patient received an integrated boost with a TD/SD of 70/2.3 Gy. No side effects have been observed so far during a median follow-up of 15.5 months. No separation between tumor and myelon could be observed in 3 patients.
Conclusion: Myelo-CT offers a distinct delineation of the myelon and the paraspinal tumor in case of artifacts due to metal implants after surgery. Using this tool in combination with advanced image guidance and IMRT techniques, patients with relatively radioresistent paraspinal tumors might have the chance of improved local control using higher target doses.

Key Words: Myelo-CT · Paraspinal tumor · Helical tomotherapy

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Wiederentdeckung eines alten Werkzeugs: CT-Myelographie für die Hochdosisbestrahlung von spinalen und paraspinalen Tumoren mit der helikalen Tomotherapie

Hintergrund: Hochdosisbestrahlung oder Rebestrahlung von spinalen und paraspinalen Tumoren ist eine Herausforderung, besonders in Gegenwart von Metallartefakten nach Operation. Bildgeführte intensitätsmodulierte Radiotherapie liefert eine hohe Strahlendosis auf den Tumor unter Schonung des Rückenmarks. Daher ist eine genaue Abgrenzung des Rückenmarks notwendig, um die Behandlung para- und intraspinaler Tumoren mit einer ausreichenden Dosis durchführen zu können.
Patienten und Methoden: Die Verwendung eines Myelo-CT wurde bei 23 Patienten mit spinalen und paraspinalen Tumoren untersucht. Alle Patienten hatten Voroperationen mit Metallimplantaten im Bestrahlungsbereich. Alle Patienten hatten eine Indikation zur Hochdosisbestrahlung. Die Bestrahlungsplanung erfolgte mit einem nativen CT und einem Myelo-CT in gleicher Lagerung und Immobilisation. Die beiden CT-Scans wurden fusioniert. Die Bestrahlung erfolgte mittels einer Tomotherapieeinheit.
Ergebnisse: Die Konturierung des Myelon in allen Schichten des Myelo-CT war bei 20/23 Patienten möglich. Alle diese Patienten wurden erfolgreich mit einer medianen Dosis von 69.4 Gy in 2-Gy-/1,8-Gy-Einzeldosen behandelt. Ein Patient erhielt einen integrierten Boost mit einer GD/ED von 70/2,3 Gy. Bei einem medianen Follow-up von 15,5 Monaten wurden keine Nebenwirkungen der Behandlung festgestellt. Eine Abgrenzung des Myelon vom Tumorgewebe war bei 3 Patienten nicht möglich.
Schlussfolgerung: Das Myelo-CT führt zu einer deutlichen Abgrenzbarkeit des Myelons von paraspinalen und spinalen Tumoren bei Metallartefakten nach Operation. Mit diesem Werkzeug in Kombination mit modernen IMRT-Techniken, könnte eine Verbesserung der Lokalrezidivrate bei Patienten mit relativ radioresistenten paraspinalen Tumoren erreicht werden.

Schlüsselwörter: Myelo-CT · Paraspinaler Tumor · Helikale Tomotherapie

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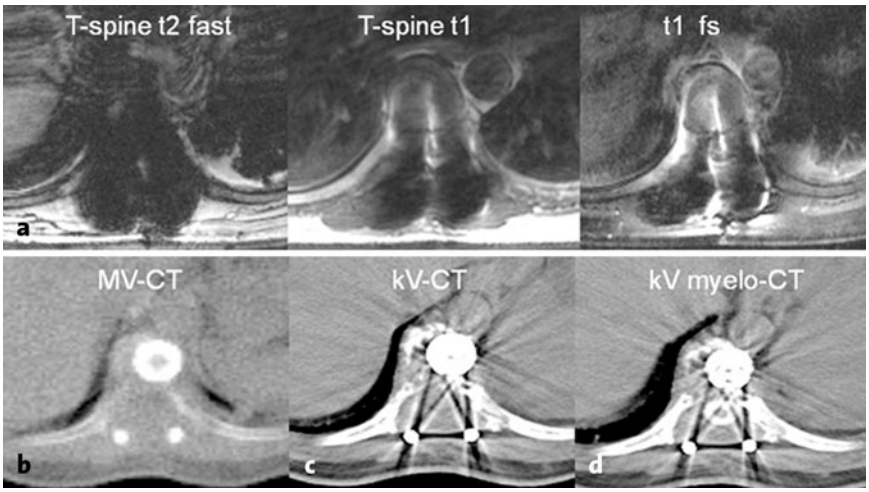
Introduction

The management of paraspinal tumors with low radiosensitivity is a challenge [20] and there is still no consensus for treatment. Pain and other neurological failures are associated with treatment. An en bloc resection of the tumor is difficult to achieve and microscopic disease often remains. Postoperative radiotherapy plays a role in improving local control [5, 21]. A challenge for the delivery of an effective dose to the target is the tolerance of the spinal cord. The spinal cord dose limits in the literature are between 45 and 50 Gy given to the full cross section of the cord [4, 10, 14]. A dose of 50–60 Gy does not lead to a long-term control but reduces the symptoms [2, 3]. For sufficient local control of, e.g., chordomas or sarcomas, a dose > 66/70 Gy is necessary [15]. The treatment of spinal and paraspinal tumors with new techniques like IMRT, in combination with image guidance, deliver a highly conformal radiation in a safe manner, allowing increase dose to the tumor, while sparing normal tissue [6, 7, 11, 16, 17, 23]. It is necessary to precisely delineate the spinal cord to spare myelon, while treating the tumor with high-dose irradiation. New MRI sequences seem to be more accurate for delineation of the myelon and the tumor; however, in the case of metal artifacts after surgery, segmentation of normal tissue might be difficult with MRI and CT (Figure 1) [1, 13, 22].



Figures 1a to **1d. a** MRI with metal artifacts. No delineation of the myelon possible. **b** MV-CT for daily image guidance. **c** kV-CT before myelography. **d** kV-CT after myelography.

Abbildungen 1a bis 1d. a MRI mit Metallartefakten. Abgrenzung des Melons nicht möglich. **b** MV-CT zur täglichen Lagekontrolle. **c** kV-CT vor der Myelographie. **d** kV-CT nach der Myelographie.

Patients and Methods

The use of myelo-CT for treatment planning was evaluated in 23 patients with spinal or paraspinal tumors between 2007 and 2009. The median age of the 23 patients was 57 years (range, 19–75); there were 7 women and 16 men. The histology of the tumors is listed in Table 1. The medullar segments were cervical, thoracal, and lumbal in 6, 14, and 3 patients, respectively. All had had surgery previously, with either incomplete (n = 18) resection or marginal (n = 5) resection of the tumor, most of them with partial or total vertebrectomy and consecutive substitution of it. All of the 23 patients included had metal implants after surgical stabilization in the treatment area. While 13 patients had never been irradiated previously, 2 patients with a sarcoma in the vertebral bodies of the thorax were treated about 20 years ago due to Hodgkin's disease. One patient with a metastasis was treated five times at different locations and once in the current treatment area 5 years ago. The others with metastasis had also received irradiation in the current treatment area before. Two patients with chordoma previously underwent irradiation next to the current treatment area and two of them in the treatment area (Table 2). All patients had an indication for high-dose irradiation or reirradiation.

Treatment planning was performed by using nonenhanced CT and enhanced myelo-CT in the same position and immobilization (Figure 1). For the enhanced myelo-CT, the contrast agent was applied into the subarachnoidal space (Figure 2). For matching both CTs, contouring of the target volume and the organs of risk, Siemens Oncologist software was used. Inverse treatment planning and treatment was performed by using the

Table 1. Patients and tumor characteristics.

Tabelle 1. Patienten- und Tumorcharakteristika.

Characteristic	Value
Age, years)	
Median	57
Range	19–75
Gender, n	
Male	16
Female	7
Histologic type, n	
Chordoma	11
Meningeoma	1
Sarcoma	4
Histiocytoma	1
Giant cell tumor	2
Renal cell carcinoma	2
Hemangioperycytoma	1
Lung tumor	1
Lesion type, n	
Primary	19
Metastatic	4
Previous treatment, n	
Surgery	23 (100%)
Radiotherapy	8

Table 2. Tumor site, tumor type, pretreatment, prescribed dose (total dose/single dose), and median/mean dose of the planning target volume (PTV).

Tabelle 2. Tumorsitz, Tumorart, Vorbehandlung, verschriebene Dosis (Gesamtdosis/Einzeldosis) und die mediane/mittlere Dosis des Planungszielvolumens (PTV).

Patient	Diagnosis	Type	Site	Surgery	Previous radiotherapy	Prescribed TD/SD, Gy	PTV Median/Mean, Gy
1	Chordoma	Primary	T9–L1	Yes	No	70/2	69.5/69.1
2	Chordoma	Primary	T3–T8	Yes	No	70/2	69.5/68.8
3	Chordoma	Primary	C5–7	Yes	C2–4, 70 GyE C12, 2000	70/2	69.8/69.1
4	Chordoma	Primary	C1–7	Yes	No	70/2	69.5/69.3
5	Chordoma	Primary	T12–L2	Yes	No	70/2	69.7/69.4
6	Chordoma	Primary	C3–4	Yes	No	70/2	68.9/68.3
7	Chordoma	Primary	C7–T2	Yes	No	70/2	69.3/68.7
8	Chordoma	Primary	C2–4	Yes	C2–6, 45 Gy + boost C3–5, 9 Gy, 2000	70/2	69.6/67.0
9	Chordoma	Primary	T1–2	Yes	No	70/2	69.7/69.1
10	Chordoma	Primary	T9–12	Yes	L1–4, 59.4 Gy, 2001	70/2	69.7/69.1
11	Chordoma	Primary	L5	Yes	L5, 44 Gy, 2007	24/2	23.9/24.0
12	Meningeoma	Primary	T2–5	Yes	No	57.2/1.8	57.5/57.0
13	Sarcoma	Primary	T8–10	Yes	mediast./supra., 40 Gy, 1990	50/2	49.4/49.7
14	Sarcoma	Primary	T1–6	Yes	mediast./spleen, 40 Gy, 1990 total nodal irradiation, 26 Gy	60(70)/2(2.33)	60.1/60.9
15	Sarcoma	Primary	T6–11	Yes	No	66/2	65.4/66.4
16	Histiocytoma	Primary	T8–L3	Yes	No	60/2	60.0/60.0
17	Giant cell tumor	Primary	C6–T1	Yes	No	66/2	65.9/65.6
18	Giant cell tumor	Primary	T6	Yes	No	70/2	69.5/68.7
19	Renal cell carcinoma	Metastatic	T11–L1	Yes	T11–L2, 30 Gy, 2007	36/2	35.7/34.6
20	Hemangiopericitoma	Metastatic	T4–6	Yes	calvarium, 63 Gy, 2000 T5–7, 56 Gy, 2002 Os ileum, 59.4 Gy, 2003 Scapula right, 55.8 Gy, 2004 Occipital, 45 Gy, 2004	30.6/1.8	30.5/30.4

Tomotherapy HighArt system, which offers a daily MV-CT guided IMRT (Figures 1 and 3).

Results

Contouring the myelon in all slices of the planning CT, using the myelo-CT for matching, was possible in 20 of the 23 patients with spinal or paraspinal tumors. All of them were treated with helical tomotherapy with doses of median 69.4 Gy in 2 Gy single doses and in two cases with a single dose of 1.8 Gy. One patient was treated with an integrated boost to the GTV of 70 Gy in 2.3 Gy single doses. The dose to the spinal cord was limited to the tolerance dose using an alpha/beta of 2 Gy for the myelon in order to take lower fraction doses into account.

Of the 11 patients with cordoma, 10 were treated with an average dose of 68.7 Gy, while 1 patient, who was pretreated with 44 Gy in another department without sparing the spinal cord, received a boost with 24 Gy on average while sparing the myelon. The 2 patients with giant cell tumor were treated with an average dose of 65.6 and 68.7 Gy, 2 patients with sarcoma received a mean dose of 49.7 and 66.4 Gy, another was irradiated with 60.9 Gy on average and 70 Gy given as an integrated boost, respectively, and the women with histiocytoma were treated with a 60.0 Gy mean dose. The metastases were irradiated with an average dose of 34.6 Gy and 30.4 Gy (1.8 Gy SD). On average, 57.0 Gy (1.8 Gy SD) was administered for meningeoma. No side effects of the CT myelography and no short-term toxicity from the irradiation were observed during the median follow-up time of 15.5 months.

No separation between tumor and myelon using myelo-CT could be observed in 3 patients. These 3 patients—1 with chondrosarcoma, 2 with bone metastasis—were treated without myelon sparing using a conservative dose regime.

Discussion

Effective treatment of spinal or paraspinal tumors is a challenge. A sufficient dose to the tumor, while sparing the spinal cord, is necessary. A dose–response relationship in local control rates has been suggested for many tumors [24]. Therefore, an accurate delineation of the spinal cord and high-dose irradiation is essential while sparing the myelon. In normal kV-CT, precise delineation of the myelon is not possible because of intense artifacts. MRI is also limited in these cases because of the metal artifacts and postoperative variances. We were able to demonstrate that myelo-CT enables a distinct delineation of the my-

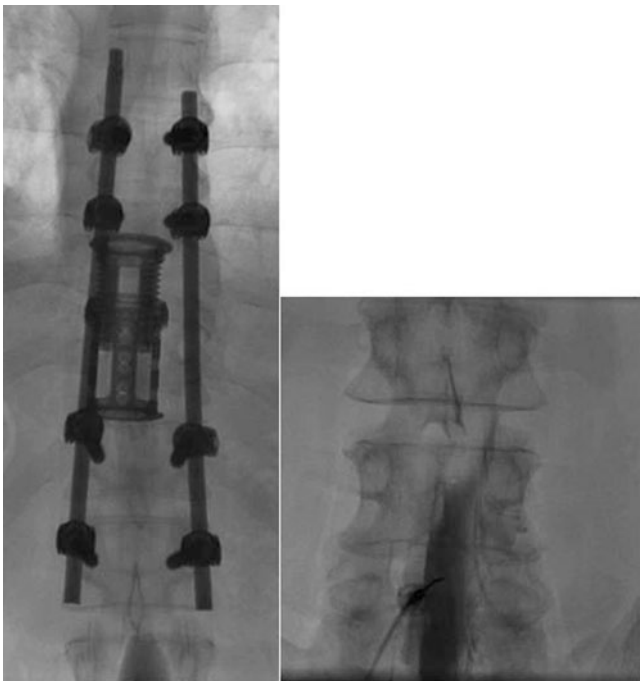


Figure 2. Application of contrast agent into the subarachnoidal space in a patient with metal instrumentation after surgery.

Abbildung 2. Applikation von Kontrastmittel in den Subarachnoidalraum bei einem Patienten mit Metallimplantaten nach erfolgter Operation.

elon and the paraspinal tumor in case of metal artifact, due to metal implants after surgery. Thariat et al. [22] also showed an advantage in planning of cyber knife stereotactic radiosurgery of spinal tumors in patients with postoperative metal material, a previous irradiation or intramedullary tumors by using myelo-CT instead of 3D-FIESTA MRI.

Myelo-CT will be an important tool for treatment planning of paraspinal tumous and metal artifacts until there is a new MRI sequence which offers equal delineation. A disadvantage of this technique is the need of two planning CTs, one enhanced and one nonenhanced myelo-CT. For the planning and for the daily image guidance the nonenhanced CT, which was fused with the enhanced myelo-CT before, was used, because of the better contrast between the vertebral body and the cerebrospinal fluid in the nonenhanced one (Figure 2). A precondition for the injection of contrast medium in the cerebrospinal fluid is a tumor-free area around the puncture. In 3 patients, it was not possible to delineate the myelon from the tumor because there was no more flow of the cerebrospinal fluid between tumor and spinal cord. In such cases, a myelo-CT is not helpful.

Helical tomotherapy delivers a highly conformal dose distribution while sparing the normal tissue [9, 12, 18, 19, 25]. A dose gradient of 10% per mm and positioning of the patient within 1.2 mm without using a special stereotactic immobilization is possible [8]. Hence, we used safety mar-

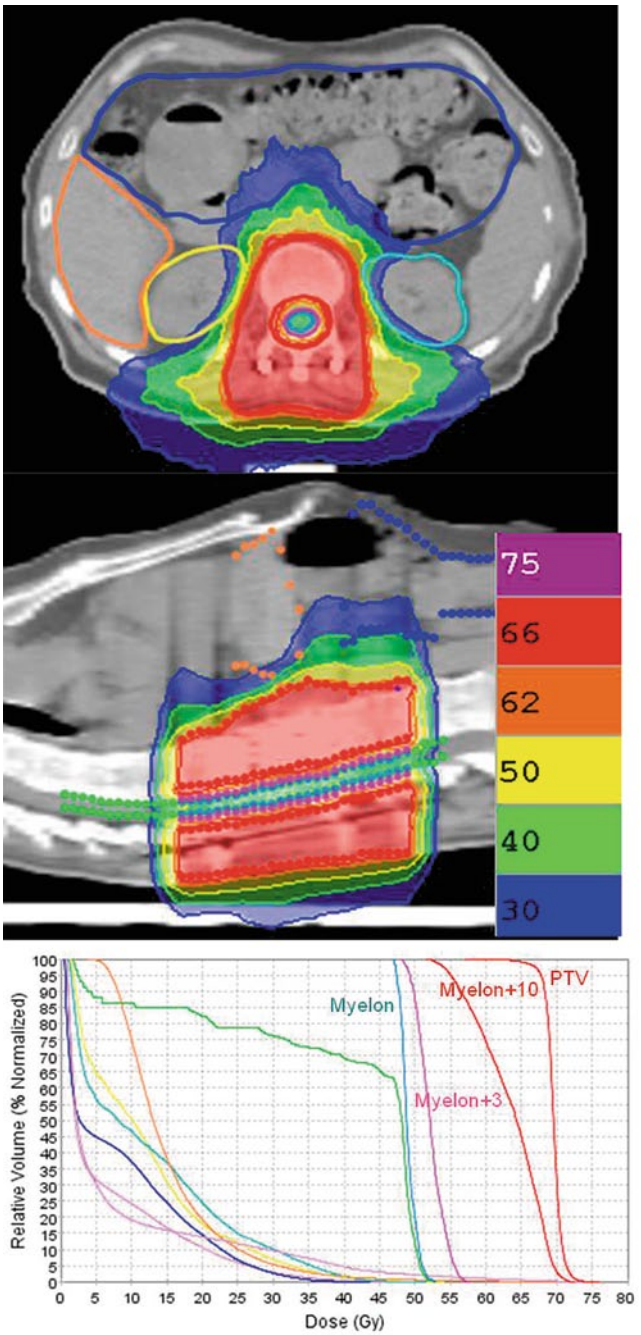


Figure 3. Dose distribution and dose volume histogram of a patient with chordoma. Myelon, myelon+3, and myelon+10 are the intersections with the PTV.

Abbildung 3. Dosisverteilung und Dosis-Volumen Histogramm eines Patienten mit Chordom. Myelon, Myelon+3, und Myleon+10 sind jeweils Schnittmengen mit dem PTV.

gins of 3 mm around the spinal cord and a daily image guidance with the integrated MV-CT. Calculating the biological equivalent dose within the safety margin of 3 mm, the TD5/5

of 50 Gy was not exceeded [4, 10, 14, 24], while treating the tumor with a sufficient dose (Figure 3). By using the myelo-CT in combination with advanced image guidance and IMRT techniques, patients with relatively radioresistent paraspinal tumors might have the chance of improved local control using higher target doses. Further follow-up for the local control rate is warranted.

Conclusion

Myelo-CT is a valuable tool for the radiation treatment of patients with relatively radioresistent spinal and paraspinal tumors in the presence of metal implants around the target.

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