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Postoperative Tumor Imaging

Laura W. Bancroft, M.D.^{1,2,3}

ABSTRACT

Accurately interpreting the imaging findings in patients with prior musculoskeletal tumors can be difficult. Because most patients have anatomical changes related to surgery in addition to postradiation and postchemotherapy changes, the radiologist must systematically and critically evaluate all available radiographs, sonograms, computed tomography, magnetic resonance imaging, and positron emission tomography/computed tomography scans to best differentiate normal posttreatment changes from residual or recurrent musculoskeletal tumor. Comparison with presurgical and postsurgical imaging is very important to detect subtle nodular tumor recurrence. Because postoperative fluid collections are relatively common, the radiologist must be vigilant for any nodular-enhancing foci that are actually residual or recurrent tumor.

KEYWORDS: Postoperative, MRI, musculoskeletal, tumor

Deciphering the postoperative imaging appearance of the patient with prior musculoskeletal imaging can be difficult. Patients with a history of treated soft tissue or osseous tumors often have a combination of postsurgical, postradiation, and postchemotherapy changes on their imaging studies. Postoperative alterations in anatomy, fibrosis, edema, and metallic susceptibility artifact can make imaging interpretation complex. Knowledge of the expected posttreatment changes on radiographs, sonography, computed tomography (CT), and magnetic resonance imaging (MRI) is critical to differentiate this from residual or recurrent musculoskeletal tumor.

RESECTION

One of the most common treatments for osseous and soft tissue tumors is surgical resection. Knowledge of the exact surgical procedure can be helpful to the radiologist to make the most accurate imaging diag-

nosis. Depending on the histology and behavior of a particular tumor, different types of surgical margins are planned. Intralesional margins will leave microscopic evidence of lesion at the margin after debulking or curetting (Fig. 1). With marginal margins, the lesion is shelled out (usually within a pseudocapsule) and no normal tissue is removed. A wide margin is accomplished when a soft tissue tumor, its pseudocapsule, and a cuff of normal tissue peripheral to the tumor are removed circumferentially en bloc.¹ A radical margin is acquired when tumor and the entire involved compartment are excised. Malignant osseous and soft tissue tumors require a wide marginal excision to minimize risks of residual or recurrent tumor (Fig. 2).

Radiographs are the most common imaging modality used to evaluate the initial postsurgical changes of osseous tumor resection, although recent postoperative MRIs are often obtained to serve as a baseline for future comparison. MRI, positron emission

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Figure 1 Aneurysmal bone cyst of C2. (A) Lateral cervical spine radiograph obtained in a 9-year-old boy demonstrates a lytic lesion in the C2 vertebra that exhibits most expansile remodeling in the posterior elements (arrow). (B) Sagittal two-dimensional computed tomography reconstruction and (C) three-dimensional surface rendered image from the posterior projection demonstrate the normal postoperative imaging findings after vertebrectomy and strut graft placement, anterior spinal plate and screw fixation, C2-3 posterior decompression, and cervicocranial fusion.

tomography/computed tomography (PET/CT), enhanced CT (if there is a contraindication to MRI or there is excessive susceptibility artifact from hardware), or sonography are used for surveillance of soft tissue lesions. MRI and PET/CT are also useful in the detection of marrow-replacing tumor recurrences.

LIMB SALVAGE PROCEDURES

Resection of a musculoskeletal tumor without amputation (limb salvage) can be accomplished in ~80% of patients with sarcomas, and patients generally prefer this over amputation because of superior function, cosmetic results, psychological reasons, and other

Figure 2 Internal hemipelvectomy for osteosarcoma. (A) Anteroposterior (AP) radiograph of the right hemipelvis in a 21-year-old woman with a several month history of right buttock pain demonstrates osteoid mineralization (arrows) about the right superior and inferior pubic rami. (B) Axial T1-weighted image shows a corresponding lobulated soft tissue mass (asterisks) that is heterogeneously hyperintense due to osteoid production. (C) AP radiograph of the pelvis after internal hemipelvectomy demonstrates wide resection of the bilateral pubic bones, right acetabulum, and right proximal femur. Note also the proximal femoral fixation screws and soft tissue suture anchors in the right lateral iliac wing and left superior pubic ramus.

factors.^{1,2} Resection of the involved segment of bone may lead to compromised mechanical support; therefore, reconstruction with bone grafting, synthetic constructs, or metallic fixation may be required. For example, if a partial sacrectomy is performed for a large chordoma or chondrosarcoma, the addition of fibular strut grafts with or without rod fixation may be needed as part of a two-stage procedure (Figs. 3 and 4).^{3,4}

Cadaveric intercalary and osteoarticular allografts serve as biological reconstruction after sarcoma resection, especially in young children.⁵ These allografts are chosen preoperatively to nearly replicate the contour and size of the resected bone, thereby maximizing function (Fig. 5).⁵ Allograft-prosthetic composite reconstruction can also be used for the treatment of osseous tumors. This technique combines a cadaveric intercalary or osteoarticular graft with an endoprosthesis, after definitive resection of the tumor (Fig. 6).^{6,7}

Osseous tumor resection and immediate reconstruction with an endoprosthesis allow patients to

return rapidly to full weightbearing and functional activities.⁸ Joint replacement with a megaprosthesis is almost always performed for a femoral tumor with skip lesions or massive intramedullary extension of a diaphyseal sarcoma.⁹ Total femoral megaprotheses replace the hip and knee joints. Complications of megaprotheses include dislocation, local recurrence, periprosthetic fracture, and deep infection.^{9,10} Radiographs are the first imaging modality to evaluate most of these complications, with higher level imaging added as needed.

Arthrodesis with large bone grafts or more unusual types of limb salvage procedures may be alternatively performed for patients with musculoskeletal malignancies. Amputation and reimplantation of the upper extremity have been reported in the literature.¹ Despite gross shortening of the limb, patients typically have better function compared with amputation and utilization of an external prosthesis.

Figure 3 Partial sacrectomy with fibular strut graft placement for chordoma. (A) Sagittal T2-weighted image through the midsacrum demonstrates a large soft tissue mass (asterisk) emanating from the S3-5 segments and obliterating the coccyx in this 47-year-old woman with progressive coccygeal pain for 2 to 3 years. (B) Three-dimensional (3D) surface rendered image obtained after the initial sacral resection delineates the margin of the resection bed. (C) 3D surface rendered image after the second surgery displays the added fibular strut grafts (arrows) that serve as structural support after partial sacrectomy.

Rotationplasty is an uncommon surgical procedure in which the distal femur and knee joint are resected, the lower leg is rotated 180 degrees, and the remaining limb is fused. This technique is used to treat patients with osteosarcoma of the distal femur, especially in skeletally immature patients; when amputation is needed to achieve adequate margins; or when endoprosthesis placement would result in leg-length discrepancy from loss of growth.¹¹ In addition, rotationplasty can be used in patients with failed reconstructions after resection of tumors around the knee.¹² Although cosmetically deforming, rotationplasty is a reasonable alternative to amputation, arthrodesis, or endoprosthesis because of its superior function. Rotationplasty allows active movement of the knee by the rotated foot with preserved sensation.¹² There are also no problems with neuroma or phantom pain.¹² Because metallic hardware is rarely used to achieve fixation, there is no susceptibility artifact limiting the detection of residual or recurrent tumor (Fig. 7). However, rotationplasty has potential complications including vascular compromise, pathologic fracture, nerve palsy, and wound complications.^{13,14}

AMPUTATION

When limb-sparing surgery is not an option, amputation is performed as the definitive treatment of malignant osseous or a soft tissue tumor. On rare occasions, aggressive tumors with benign histology (such as desmoid tumors) can be so infiltrative and painful that amputation may be the treatment of last resort (Fig. 8).

Imaging may be prompted to evaluate an amputee with pain. Radiography can be helpful in diagnosing some postsurgical problems, specifically an aggressive bone edge, heterotopic ossification, or osteomyelitis.¹⁵ In addition, stump neuromas are common in amputees. Terminal neuromas occur along the distal portion of the transected nerve after amputation because the proximal axons grow and form an extremely sensitive bulbous overgrowth.¹⁶ These lesions occur within 1 month to 1 year after amputation, may enlarge for 2 to 3 years, and can result in stump pain.¹⁶ Terminal neuromas are ovoid, well-defined, or irregularly margined nodules in direct continuity with the nerve on sonography, and they are seen as bulbous expansion of the transected nerve on MRI or CT (Fig. 9).¹⁶ Sonography is useful for the detection of these lesions, and it serves as image guidance for percutaneous steroid injection.¹⁶

Figure 4 Chondrosarcoma sacrectomy with fibular strut grafts. A 53-year-old man presented with a 3-year history of worsening left leg pain and new back pain radiating to the posterior left thigh and calf weakness. (A) Coronal two-dimensional reconstruction through the sacrum demonstrates a lytic mass with chondroid mineralization in the S1 and S2 bodies, with extension into the left-sided wing. Note the destruction of the left S1 neural foramina and obliteration of the involved portion of the S1 nerve. (B) Radiograph obtained after en bloc excision of the grade 1 chondrosarcoma and staged reconstruction with fibular allograft, lumbosacral pedicle screw, and iliac fixation.

Figure 5 Distal radial resection, osteochondral allograft, and Suave-Kapandji procedure for osteosarcoma. Radiograph of the distal forearm and wrist in a 24-year-old woman shows bone grafting (arrowhead) and plate and screw fixation across the distal radial osteochondral allograft (arrows). A Suave-Kapandji procedure (distal ulnar osteotomy with distal radioulnar fixation) has also been performed to provide stabilization of the distal radioulnar joint. Kirschner wires were temporarily placed for added stabilization.

MYOCUTANEOUS FLAPS

Myocutaneous flaps can be used for soft tissue coverage after the resection of soft tissue malignancy. Flaps are either free flaps with reanastomosed vascular pedicles or rotational flaps placed into a soft tissue defect. It is important to be familiar with the postoperative appearance of myocutaneous flaps so as not to confuse them with recurrent or residual tumor (Fig. 10). Flaps initially demonstrate increased T2-weighted signal intensity but will revert to baseline signal in about a third of patients.¹⁷ Findings are likely related to a combination of denervation, disuse, and radiation changes (when administered). Myocutaneous flap enhancement occurs in three fourths of patients but typically resolves in one third of cases within 18 months.¹⁷ Myocutaneous flaps also undergo progressive fatty atrophy.

TUMOR RECURRENCE

Optimal imaging interpretation depends on knowledge of when a musculoskeletal tumor was resected, histologic tumor grade, and whether or not tumor-free surgical margins were achieved. Despite abnormal MR signal in and around the surgical bed in a recently postoperative patient with negative surgical margins, imaging support for residual/recurrent tumor is highly unlikely. Recurrent osseous or soft tissue musculoskeletal tumors are often detected as rounded or ovoid

Figure 6 Allograft-prosthetic composite for chondrosarcoma of the femur. (A) Coronal two-dimensional reformatted computed tomography image of the left proximal femoral chondrosarcoma (arrows) delineates the “arcs and rings” type of chondroid mineralization, with focal areas of endosteal scalloping (arrowheads) at regions of more aggressive behavior. (B) Postoperative radiograph shows proximal femoral resection and placement of an allograft (large arrows) bipolar prosthesis composite graft. Also note the lateral femoral onlay allograft (arrowheads) anchored with Dall-Miles cables that provides added stability at the junction (long arrow) between the allograft (short arrows) and native femur.

nodules, and they often have a similar imaging appearance to the original tumor (Fig. 11). Therefore, direct comparison with preoperative imaging is very useful in the detection of early subtle tumor recurrence. The “muscle texture” sign on MR imaging is the presence of linear or streaks of fat between muscle bundles and indicates no underlying soft tissue mass to suggest recurrence (Fig. 12).^{18,19}

If an osseous tumor has been curetted and packed with bone graft or cement, recurrent tumor most often recurs along the cement/graft margin (Fig. 13).¹⁸ If available, surveillance MRI is advised in patients after resection of musculoskeletal sarcoma because ~20% of all sarcomas and 30% of all resected sarcomas with positive margins recur.^{1,20} Susceptibility artifact from metallic fixation may obscure small recurrences on MRI and CT (Fig. 14), although MRI techniques are available to decrease artifact such as increasing receiver bandwidth, increasing matrix size, using fast spin-echo imaging and avoiding gradient-echo sequences. Sonography has proven useful in experienced hands for the detection of nodular soft tissue recurrence.

Tumor recurrence can usually be differentiated from postoperative fluid collections such as seromas and hematomas. Tumor foci are typically round or ovoid, hypoechoic on sonography, T2 hyperintense on MRI, and demonstrate internal vascularity on color flow Doppler imaging and enhancement on MRI.^{17,21} In contradistinction, seromas are typically anechoic or hypoechoic, ovoid or irregular, and may contain a dark

pseudocapsule on sonography.^{21,22} Seromas may demonstrate internal swirling of contents, compressibility, posterior acoustic enhancement, and lack of internal vascularity.^{21,22} However, certain histological types of tumors can be difficult to distinguish from postoperative fluid collections, such as recurrent low-grade chondroid lesions and myxoid sarcomas. The cartilage lobules within low-grade chondrosarcoma do not enhance, and only minimal lacelike enhancement may be appreciated in myxoid lesions such as myxoid liposarcoma and undifferentiated pleomorphic sarcoma.¹⁸ Therefore, small recurrences may be overlooked and misdiagnosed as postsurgical fluid collections.

Residual/recurrent benign and malignant fibrous tumors (i.e., desmoid tumor and fibrosarcoma) have low-signal intensity components that may be misdiagnosed as scar tissue on MR imaging.¹⁸ In addition, fibrosarcoma has a tendency to infiltrate beyond the primary tumor bed, resulting in multifocal, noncontiguous tumor deposits.¹⁸ Care must be taken in the interpretation of these postoperative studies not to overlook residual or recurrent malignancy. In indeterminate cases, image-guided biopsy or 3- to 6-month imaging follow-up may be prudent for follow-up.

POSTTREATMENT MARROW CHANGES

Radiation therapy often results in increased yellow marrow in the irradiated field, with complete replacement of the red marrow on imaging at 6 to 8 weeks

Figure 7 Osteosarcoma recurrence in the tibia after rotationplasty for femoral primary lesion. (A) Sagittal fast spin-echo T2-weighted image through the distal femur in a 10-year-old boy demonstrates a heterogeneous, hyperintense tumor (asterisk), which proved to be pathologically proven osteogenic sarcoma. (B) Positron emission tomography/computed tomography (CT) image obtained 5 years after rotationplasty for limb salvage procedure shows a focus of increased metabolic activity (asterisk) in the rotated distal tibia near the arthrodesis, corresponding to (C) a lytic destructive lesion (asterisk) on CT. Lesion proved to be recurrent osteosarcoma, and above-the-knee amputation was subsequently performed.

Figure 8 Desmoid. (A) Axial fast spin-echo T2-weighted fat-suppressed image through the proximal calf demonstrates a large heterogeneous mass involving the entire posterior compartment, consistent with desmoid tumor. (B) Because of unrelenting pain despite multiple debridements and chemotherapy, the patient elected to undergo above-the-knee amputation.

Figure 9 Popliteal stump neuroma. Sagittal T1-weighted image through the thigh after below-the-knee amputation shows bulbous enlargement of the distal portion of the transected popliteal nerve, consistent with terminal stump neuroma (arrow).

Figure 11 Sarcoma recurrence within rectus myocutaneous flap. Axial T1-weighted image through the lower pelvis in a 72-year-old man displays an intensely enhancing nodule (arrow) in the left groin myocutaneous flap, which proved to be recurrent grade 3 undifferentiated pleomorphic sarcoma.

A

B

Figure 10 Rectus abdominis rotational myocutaneous flap. (A) Coronal T1-weighted image through the anterior pelvic wall delineates rotation of the left rectus abdominis muscle from its native position (asterisk) into the left groin. Flap was placed for soft tissue coverage after synovial sarcoma resection. (B) Schematic drawing of rectus abdominis rotational flap with preservation of the vascular pedicle (arrow shows rotational direction).

Figure 12 “Muscle texture” sign. Sagittal T1-weighted image through a rotational gastrocnemius flap demonstrates the presence of linear fat (arrows) between muscle bundles, indicating there is no underlying soft tissue mass to suggest tumor recurrence.

(Fig. 15).¹⁷ Radiation doses >50 Gy can result in complete bone necrosis, and lesser doses can make the irradiated bone more prone to fracture.^{23,24} Radiation osteitis occurs in a third to a half of patients receiving radiation therapy, and abnormal marrow signal has been reported 9 to 42 months after treatment.¹⁷ Cryotherapy is being used more frequently to treat musculoskeletal tumors and can also result in marrow necrosis or marrow edema-like signal changes.¹⁸ Bone allografts used for limb salvage surgery can result in abnormal marrow signal on MRI due to fat, gelatinous material, and fibrovascular tissue.¹⁸

RADIATION-INDUCED SARCOMAS

Radiation-induced sarcomas are rare and occur in the soft tissues more than two times more frequently than in bone.¹⁷ Radiation-induced sarcoma of bone is an uncommon sequela that occurs an average of 13 to 14 years after radiotherapy, with a minimum of a 5-year history of latency.^{23,25,26} These aggressive sarcomas tend to develop within or at the margin of the irradiated field, have

Figure 13 Recurrent giant cell tumor. (A) Recurrent giant cell tumor (arrows) in the medial femoral condyle extends along the cement (asterisk) that was placed after curettage of the original lesion. Intra-articular extension of tumor is seen to better advantage after arthrography. (B) Sagittal T1-weighted and (C) axial fast spin-echo T2-weighted images in a 39-year-old man show a larger focus of recurrent giant cell tumor (arrows) extending about the proximal humeral cement (asterisks).

Figure 14 Tumor recurrence around humeral prosthesis. (A) Sagittal two-dimensional computed tomography reconstructed image through the humerus shows a pathological fracture through the lytic destructive lesion through the midhumerus, which proved to be malignant fibrous histiocytoma (MFH). (B) Coronal T1-weighted enhanced magnetic resonance imaging through the left humerus 2 years after tumor resection and rod fixation shows recurrent MFH with central necrosis and a nodular, enhancing border (arrows). Susceptibility artifact (asterisks) is from metallic rod.

Figure 15 Radiation changes of the bones. (A) Sagittal T1-weighted image through the lumbosacral spine shows complete fatty replacement of the sacrum, corresponding to extent of the radiation field. (B) Sagittal fast spin-echo T2-weighted fat-suppressed image obtained in an 85-year-old woman who was treated 19 months previously with 5040 cGy of external-beam radiation for leiomyosarcoma of the left medial thigh demonstrates new heterogeneous, hyperintense marrow signal in the anterior distal femoral medullary canal (arrow). Biopsy was not performed, and subsequent follow-up magnetic resonance imaging showed no discrete mass and progressive changes consistent with radiation osteitis.

Figure 16 Synovial sarcoma development after radiation therapy. (A) Positron emission tomography/computed tomography image through the lower pelvis shows a hypermetabolic focus within an ovoid nodule in the right groin (arrow). (B) Coronal fast spin-echo T2-weighted fast-suppressed image through this region shows a correlative homogeneous, hyperintense nodule (arrow). Lesion was biopsied and proved to be synovial sarcoma.

Figure 17 Left humeral and surrounding soft tissue radiation-induced osteogenic sarcoma. (A) Axial T1-weighted and (B) fast spin-echo T2-weighted fat-suppressed images through the upper arm obtained in an 80-year-old woman who was radiated 18 years previously for immunoblastic lymphoma demonstrate a destructive mass in the proximal humerus with multilobulated soft tissue extension. Biopsy revealed grade 4/4 osteogenic sarcoma. (C) Anteroposterior radiograph of the arm after resection of the proximal half of the humerus and placement of a custom humeral arthroplasty.

a different histology than the original tumor, may develop in normal bones or ones with preexisting lesions, and occur in patients with a mean radiation dose of 43 to 64 Gy.²³ Ninety percent of radiation-induced sarcomas are either osteosarcoma or fibrosarcoma, and this subtype of osteosarcoma accounts for ~5% of all osteogenic sarcomas.²³ Chondrosarcoma, malignant fibrous histiocytoma, lymphoma, Ewing's sarcoma and metastasizing chondroblastoma are less commonly reported radiation-

induced sarcomas.²⁶ Because radiation-induced sarcomas are of a different histology than the original treated tumor, they tend to have differing MR imaging characteristics from the original tumor. However, most of these sarcomas will be round or ovoid, and they avidly enhance after the administration of contrast (Figs. 16 and 17). Patients with radiation-induced sarcoma may also present for treatment only after sustaining a pathological fracture (Fig. 18).

Figure 18 Pathological fracture through radiation-induced malignant fibrous histiocytoma of the right femur. (A) Coronal T1-weighted and (B) fast spin-echo T2-weighted fat-suppressed images through the proximal femur delineate a pathological fracture (arrow) through the destructive lesion (asterisk) in the intertrochanteric femur. (C) Intraoperative photograph and (D) anteroposterior radiograph after resection of the proximal femur show optimal placement of the custom bipolar prosthesis.

CONCLUSION

Accurately interpreting the imaging findings of treated musculoskeletal tumors can be difficult. Because these patients often have anatomic changes related to surgery and abnormal MRI signal changes related to radiation and chemotherapy, the radiologist must obtain relevant surgical and histology reports and systematically evaluate all available pre- and postsurgical imaging studies. Critical assessment of musculoskeletal CTs, MRIs, and PET/CTs is essential in differentiating normal posttreatment changes from residual or recurrent tumor. Recurrences most commonly manifest as discrete ovoid or rounded, vascular solid nodules on MRI or sonography. However, exceptions to this rule include nonenhancing lobules of cartilage in recurrent chondrosarcoma, minimally enhancing recurrent myxoid tumors, and hypointense and infiltrative fibrosarcoma or desmoid tumor simulating scar tissue. Radiologists must be aware of nontumorous osseous and soft tissue changes such as seromas and radiation changes of bone.

REFERENCES

1. Abed R, Younge D. Surgical management of very large musculoskeletal sarcomas. *Ann N Y Acad Sci* 2008;1138:77–83
2. Aksnes LH, Bauer HCF, Jebsen NL, et al. Limb-sparing surgery preserves more function than amputation: a Scandinavian sarcoma group study of 118 patients. *J Bone Joint Surg Br* 2008;90(6):786–794
3. Killampalli VV, Power D, Stirling AJ. Preadolescent presentation of a lumbar chordoma: results of vertebrectomy and fibula strut graft reconstruction at 8 years. *Eur Spine J* 2006;15(Suppl 5):621–625
4. Winters HA, van Engeland AE, Jiya TU, van Royen BJ. The use of free vascularised bone grafts in spinal reconstruction. *J Plast Reconstr Aesthet Surg* 2010;63(3):516–523
5. Muscolo DL, Ayerza MA, Aponte-Tinao L, Farfalli G. Allograft reconstruction after sarcoma resection in children younger than 10 years old. *Clin Orthop Relat Res* 2008;466(8):1856–1862
6. Abdeen A, Hoang BH, Athanasian EA, Morris CD, Boland PJ, Healey JH. Allograft-prosthesis composite reconstruction of the proximal part of the humerus: functional outcome and survivorship. *J Bone Joint Surg Am* 2009;91(10):2406–2415
7. Szabo RM, Anderson KA, Chen JL. Functional outcome of en bloc excision and osteoarticular allograft replacement with the Sauve-Kapandji procedure for Campanacci grade 3 giant-cell tumor of the distal radius. *J Hand Surg Am* 2006;31(8):1340–1348
8. Jeys LM, Kulkarni A, Grimer RJ, Carter SR, Tillman RM, Abudu A. Endoprosthetic reconstruction for the treatment of musculoskeletal tumors of the appendicular skeleton and pelvis. *J Bone Joint Surg Am* 2008;90(6):1265–1271
9. Natarajan MV, Balasubramanian N, Jayasankar V, Sameer M. Endoprosthetic reconstruction using total femoral custom mega prosthesis in malignant bone tumours. *Int Orthop* 2009;33(5):1359–1363
10. Sewell MD, Spiegelberg BG, Hanna SA, et al. Total femoral endoprosthetic replacement following excision of bone tumours. *J Bone Joint Surg Br* 2009;91(11):1513–1520
11. Salzer M, Knahr K, Kotz R, Kristen H. Treatment of osteosarcomata of the distal femur by rotation-plasty. *Arch Orthop Trauma Surg* 1981;99(2):131–136
12. Ramseier LE, Dumont CE, Exner GU. Rotationplasty (Borggreve/Van Nes and modifications) as an alternative to amputation in failed reconstructions after resection of tumours around the knee joint. *Scand J Plast Reconstr Surg Hand Surg* 2008;42(4):199–201
13. Agarwal M, Puri A, Anchan C, Shah M, Jambhekar N. Rotationplasty for bone tumors: is there still a role? *Clin Orthop Relat Res* 2007;459:76–81
14. Sawamura C, Hornicek FJ, Gebhardt MC. Complications and risk factors for failure of rotationplasty: review of 25 patients. *Clin Orthop Relat Res* 2008;466(6):1302–1308
15. Henrot P, Stines J, Walter F, Martinet N, Paysant J, Blum A. Imaging of the painful lower limb stump. *Radiographics* 2000;20(Spec No):S219–S235
16. Ernberg LA, Adler RS, Lane J. Ultrasound in the detection and treatment of a painful stump neuroma. *Skeletal Radiol* 2003;32(5):306–309
17. Garner HW, Kransdorf MJ, Bancroft LW, Peterson JJ, Berquist TH, Murphey MD. Benign and malignant soft-tissue tumors: posttreatment MR imaging. *Radiographics* 2009;29(1):119–134
18. Panicek DM, Schwartz LH. MR imaging after surgery for musculoskeletal neoplasm. *Semin Musculoskelet Radiol* 2002;6(1):57–66
19. Kotnis NA, Grimer RJ, Davies AM, James SL. Magnetic resonance imaging appearances following hindquarter amputation for pelvic musculoskeletal malignancy. *Skeletal Radiol* 2009;38(12):1137–1146
20. Watts AC, Teoh K, Evans T, Beggs I, Robb J, Porter D. MRI surveillance after resection for primary musculoskeletal sarcoma. *J Bone Joint Surg Br* 2008;90(4):484–487
21. Jacobson JA, Lax MJ. Musculoskeletal sonography of the postoperative orthopedic patient. *Semin Musculoskelet Radiol* 2002;6(1):67–77
22. Davies AM, Hall AD, Strouhal PD, Evans N, Grimer RJ. The MR imaging appearances and natural history of seromas following excision of soft tissue tumours. *Eur Radiol* 2004;14(7):1196–1202
23. Morris CD, Antonescu CR. Lower extremity swelling after treatment for thigh synovial sarcoma. *Clin Orthop Relat Res* 2004;429:342–347
24. Amendola BE, Amendola MA, McClatchey KD, Miller CH Jr. Radiation-associated sarcoma: a review of 23 patients with postradiation sarcoma over a 50-year period. *Am J Clin Oncol* 1989;12(5):411–415
25. Dickie CI, Parent AL, Griffin AM, et al. Bone fractures following external beam radiotherapy and limb-preservation surgery for lower extremity soft tissue sarcoma: relationship to irradiated bone length, volume, tumor location and dose. *Int J Radiat Oncol Biol Phys* 2009;75(4):1119–1124
26. Weatherby RP, Dahlin DC, Ivins JC. Postradiation sarcoma of bone: review of 78 Mayo Clinic cases. *Mayo Clin Proc* 1981;56(5):294–306