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Three-dimensional MRI reconstructions of musculoskeletal tumors

A preliminary evaluation of 2 cases

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We have developed a new method for three-dimensional (3D) reconstruction of malignant bone and soft-tissue tumors from MRI. Data from transverse images of T2-weighted images were transferred into a personal computer. The contours of tumors, major vessels, major nerves and bones were outlined, whereupon the 3D data were processed into a 3D display, using a solid model. The determination of tumor volume both before and after preoperative adjuvant therapy was quantified. The 3D images allowed a better understanding of the relationship between the tumor and the major vessels and nerves, thereby aiding in preoperative planning. The images also provided a quantitative, reproducible measurement of the effect of adjuvant therapy.

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Magnetic resonance imaging is useful in the diagnosis of bone and soft-tissue tumors (Aisen et al. 1986, Sundaram et al. 1986, Pettersson et al. 1987). It is believed that the tumor contour can be stereotopically perceived from MR images. However, it is not easy to interpret the tumor contour and the relationship between the tumor, the major vessels and nerves in 3 dimensions, since the separate MR images are not three-dimensional but planar. To overcome this difficulty, we have reconstructed the planar MR images of malignant bone and soft-tissue tumors into three-dimensional (3D) images. We found the 3D-MRI reconstructions to be helpful for surgical planning and the determination of the effect of adjuvant therapy.

Patients and methods

A 0.2 Tesla permanent magnet was used to acquire the MR images (MRP-2D-1, Hitachi Medico Co., Ltd., Tokyo Japan). A surface coil was applied to the lateral side of the affected extremity. A spin echo (SE) pulse sequence was used. A repetition time (TR) of 2000 or 2200 msec and an echo time (TE) of 90 or 100 msec were used for T2-weighted images. A TR of 500 msec and a TE of 25 msec were used for T1-weighted images. Multi-slice transverse imaging produced scans consisting of contiguous 2-mm slices. T2-weighted images were used for 3D reconstruction because, with them, differentiation of extra-osseous tumor from the muscles is easier than with T1-weighted images. The MRI data were then transferred to a computer (PC-9800, Nihon Denki Home Electronics Co. Ltd., Tokyo, Japan) for 3D reconstruction, using a solid model (Tsumura et al. 1991). The investigator outlined the tumor, the major vessels and the nerves from each section with a cursor. The resultant outlines were transferred onto a laser disc and then assembled by the computer to generate a 3D image. The approximate total tumor volume was quantified by integrating the volumes of each of the 2 mm-thick tumor slices, using the following integral formula:

$$\text{Tumor volume} = \sum_{i=o}^{n-1} [S_i + S_{i+1}) / 2] \times h$$

where S_i is a cross-sectional area of one slice of the tumor at i, the axis of the coordinates, while S_{i+1} is the cross-sectional area of the adjacent slice, with h as the distance (2 mm) between S_i and S_{i+1} (Figure 1).

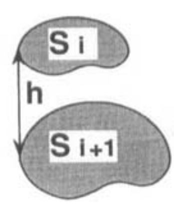
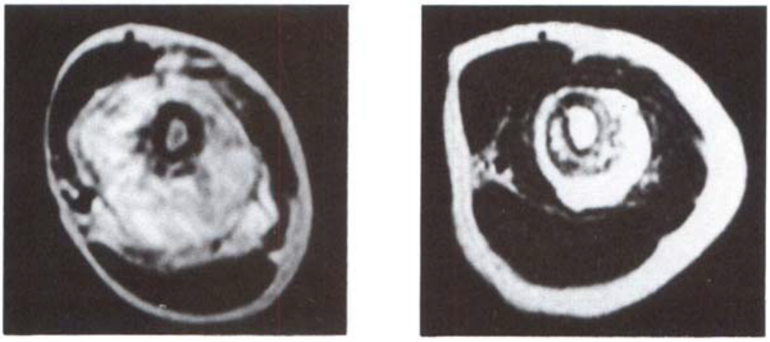
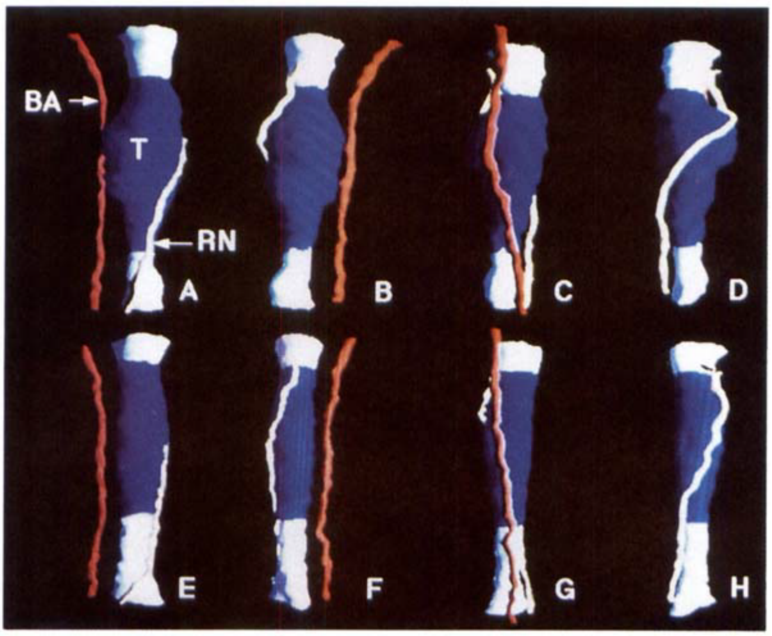


Figure 1. Diagrammatic representation of the formula for calculating tumor volume from transverse MR images. Si is the cross-sectional area of the tumor at i, the axis of the coordinates, while Si+1 is the area of the adjacent slice, with h as the distance (2 mm) between Si and Si+1.

Figure 2. ***Case 1.*** **Transverse T2-weighted MR image (TR2200/ TE100) of a neuroectodermal tumor of bone in the left humerus.**



Before adjuvant therapy. After adjuvant therapy.

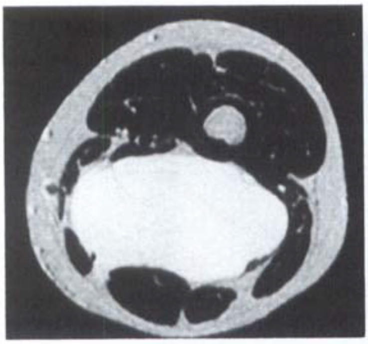


3D-MR images of the tumor. T tumor. BA brachial artery. RN radial nerve. A-D before adjuvant therapy. E-H after adjuvant therapy. A and E anterior views. B and F posterior views. C and G medial views. D and H lateral views.

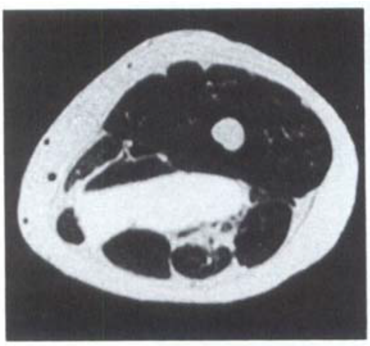
Case 1

A 13-year-old boy presented with pain, swelling and tenderness in his left upper arm. Radiographs revealed an osteolytic lesion with periosteal reaction in the humeral diaphysis. A light microscopic study of an incisional biopsy was diagnosed as a neuroectodermal tumor of bone. Preoperative adjuvant treatment included irradiation (40 Gy) and chemotherapy with vincristine, adriamycin, cyclophosphamide and actinomycin-D. T2-weighted images prior to the adjuvant therapy demonstrated a substantial extra-osseous extension of the tumor (Figure 2). MRI-examination after the adjuvant therapy revealed a marked decrease in the extra-osseous tumor extension. An anterior view of the 3D-MRI before the adjuvant therapy demonstrated that the tumor was adherent to the brachial artery. The 3-D MRI after adjuvant therapy showed that the artery was not involved. The medial view after the adjuvant therapy revealed a reduction in the posterior part of the tumor. The posterior view clearly showed the adherence of the radial nerve to the entire longitudinal axis of the extra-osseous portion of the tumor, even after the adjuvant therapy. The tumor volumes before and after the adjuvant therapy were 131 cm^3 and 61 cm^3, respectively.

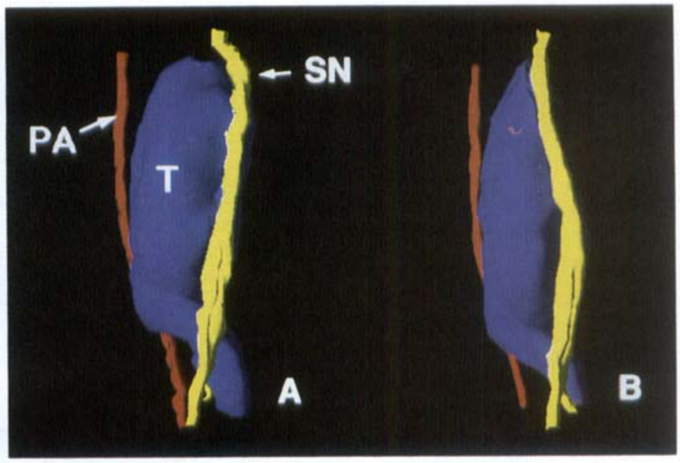
Figure 3. *Case 2.* **Transverse T2-weighted MR image (TR2000/TE90) of a myxoid liposarcoma in the left thigh.**



Before adjuvant therapy.



After adjuvant therapy.



3D-MR images of the tumor. T tumor. PA popliteal artery. SN sciatic nerve.

The 3D images after the adjuvant therapy indicated that the patient was a candidate for a limb-sparing procedure. A wide excision followed by reconstruction of the upper limb with autoclaved bone autograft was carried out. The radial nerve was resected just above and below the extra-osseous extension of the tumor. The 3D images of the tumor were helpful in our preoperative planning and in the explanation of the surgical plan to the patient's family. The histologic examination of the tumor showed no viable tumor cells. The efficacy of the preoperative therapy was consistent with the reduction in the tumor volume.

Case 2

A 28-year-old pregnant woman presented with a soft tissue tumor in the left thigh. A needle-biopsy specimen was diagnosed as a myxoid liposarcoma. The child was delivered by cesarean section, and the patient underwent preoperative radiation (32 Gy) in combination with hyperthermia for 3 weeks. T2-weighted MR images before and after the adjuvant therapy showed reduced tumor size (Figure 3). The 3D-MRI after the adjuvant therapy revealed the reduction in the tumor size and the amelioration of the posterior kinking of the sciatic nerve (Figure 3). The tumor volumes before and after the adjuvant therapy were 579 cm^3 and 297 cm^3, respectively.

Based on the 3D images, a decision was made to proceed with a limb salvage operation by a medial approach. Histologic examination of the tumor specimen revealed complete necrosis.

Discussion

3D-MRI has been recently applied to such diagnoses as lesions of the brain (Vannier et al. 1991a), skull base (Grevers et al. 1991), heart (Vannier et al. 1991b), coronary artery (Li et al. 1993), pulmonary vessels (Wielopolski et al. 1992), meniscus (Thompson et al. 1991) and scaphoid (Smith 1993), but not to bone or soft-tissue tumors. Our experiences indicate that 3D-imaging of MRI in malignant bone and soft-tissue tumors offers the following advantages: 1) the relationship between the malignant tumor and the major vessels and nerves can be precisely determined for better surgical planning; 2) a reduction in tumor size by preoperative adjuvant therapy can be clearly and quantitatively determined.

The T2-weighted MR images are thought to be better than the T1-weighted images for the determination of an extra-osseous extension of malignant bone tumors. Extra-osseous tumor is seen as a high-intensity signal and the muscles surrounding the tumor are seen as a low-intensity signal (Aisen et al. 1986, Sundaram et al. 1986, Pettersson et al. 1987). Therefore, by using T2-weighted images for the 3 D reconstruction, we were able to not only determine the relationship between the tumor and the major vessels and nerves, but also to quantify the reduction in tumor size. However, the determination of the extent of the tumor may be difficult in cases where the tumor is associated with an extensive reactive zone, since both the extra-osseous tumor and the reactive zone reveal high signal intensity in T2-weighted images. The tumor margin may also be difficult to determine in T2-weighted images, when the tumor is located subcutaneously or intramedullarly, since the subcutaneous and intramedullary fat are of low intensity. The 3D reconstruction of MRI studies, using T1-weighted images instead of T2-weighted images, may be useful in these situations.

Through the use of a programmed personal computer, we easily determined the approximate tumor volume. It is well known that the chemotherapeutic effect on malignant bone tumors may be quite heterogeneous within the tumor itself. The analysis of both the longitudinal and transverse planes of surgical specimens after preoperative chemotherapy has shown that some areas were necrotic while other areas were viable (Picci et al. 1987). Therefore, the chemotherapeutic effect on the tumor as determined in one plane of an MRI study may not represent the effect on the whole tumor. Our method of evaluating the change in tumor volume may be superior for assessing the effect of the preoperative adjuvant therapy.

We found two minor difficulties with our method of producing the 3D reconstructions. First, it takes several hours to outline the extent of tumor, the major vessels and the nerves with a cursor. Secondly, it is sometimes difficult to follow the outline of small structures with the cursor. When these problems are solved, our method for the 3D reconstruction of malignant tumors with MRI will become available for wide use among tumor surgeons specializing in lesions of the musculoskeletal system.

Acknowledgement

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