Magnetic resonance chemical shift imaging in bone and soft tissue tumours

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Summary. *A study was carried out in 14 patients to assess the location and differential diagnosis of bone and soft tissue tumours with a 0.5 Tesla scanner, using water and fat images obtained by the three-point Dixon technique. We compared the magnetic resonance imaging findings obtained with this technique with conventional MRI, T1-T2-weighted images, and gadolinium-diethylene-triamine penta-acetic acid enhanced T1-weighted images. Localisation was better with the three-point Dixon technique than with conventional magnetic resonance imaging. Differentiation between the fat and water component around the tumour was possible. The gadolinium-diethylene-triamine penta-acetic acid enhanced water images were very sensitive to enhancement of the tissue. The three-point Dixon technique is useful when the tumour area is difficult to detect by conventional magnetic resonance imaging and information about its components is needed; these images can be made at the low magnet field.*

Résumé. *Ce travail étudie la localisation tumorale et le diagnostic des tumeurs de l'os et des parties molles par la technique de Dixon (technique 3 PD) qui sépare, en résonance magnétique, les signaux d'origine grasseuse ou hydrique. Nous comparons les résultats obtenus par cette technique avec résonance magnétique conventionnelle et utilisation de Gadolinium qui réhausse les images pondérées en T1. Cette étude a été faite dans 14 cas de tumeur de l'os et des parties molles avec un appareil*

à 0.5 Tesla. La localisation des tumeurs était améliorée par la méthode de Dixon comparée à la résonance magnétique conventionnelle. La différenciation entre les composants hydriques ou gras fut aussi possible. Des images obtenues avec Gadolinium étaient très sensibles pour le réhaussement des tissus. La technique 3 PD est utile quand la détection de la zone tumorale est difficile et quand des informations sur les composants tumoraux sont nécessaires. De plus, ces images peuvent être obtenues avec un champ magnétique de faible intensité.

Introduction

Magnetic resonance imaging (MRI) presents biochemical information obtained from protons in the tissues, but with conventional imaging it is difficult to identify whether the information is coming from water or fat. Suppression of the lipid is necessary to determine the water fraction [1].

Differences in resonance between fat and water results in another type of chemical shift artifact, the relative difference being about 3.5 ppm [2]. In 1984, Dixon introduced a new method of MRI which separates the signal into a water and a fat component showing either water or fat, and producing a difference in the signal intensity between them [3]. Useful information can now be obtained at a slow magnetic field (lowest 0.35 Tesla). The technique was used for cases such as a lipoma, fatty liver or prostatic disease [4, 5, 6]. Images obtained by the conventional Dixon techniques had

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poor separation between water and fat with mixed images which had poor homogeneity.

In recent years, a modified Dixon technique has been developed [7, 8], which was useful for bone marrow disease [9, 10], but primary bone and soft tissue tumours were not analysed. We have applied the method to these lesions for diagnosis and the planning of operative treatment.

Patients and methods

Between 1990 and 1993, 14 patients with bone and soft tissue tumours were examined using standard and the 3-point Dixon techniques (3PD). The tumours were osteosarcoma in 4, Ewing's sarcoma in 3, lipoma in 2, soft tissue sarcoma in 3, and benign bone tumours in 2.

The MRI protocol included T1-weighted and T2-weighted spin echo (SE) images, gadolinium-diethylenetriamine penta-acetic acid (Gd-DTPA) enhanced T1-weighted images, the 3PD images, and Gd-DTPA enhanced 3PD images. Gd-DTPA images were obtained after intravenous injection of Gd-DTPA 0.1 mmol/kg. The 3PD technique was used to generate water and fat images. The MRI was performed with a 0.5 T scanner (Yokogawa Medical, Japan).

The 3PD technique enhances decomposition of fat and water using 3 measurements with phase shifts of 0, π and $-\pi$ between fat and water resonances [11]. The images were evaluated by one independent radiologist and two orthopaedic surgeons with considerable experience in analysing MR images. MRI findings in every case were correlated with the surgical specimen and its histology.

Results

Conventional T1- and T2-weighted SE images were compared with Dixon images. Although different techniques were used, we tried to obtain all images within 2 days, with the same orientation and slice position.

Tumour localisation

The exact area was difficult to identify on T1-weighted images if a bone tumour did not have a low signal and if iso-signal soft tissue tumours appeared in soft tissue with a lipid content. Bone tumours in fatty marrow usually showed a low signal intensity, but 3 of the 4 malignant bone tumours showed an iso- or mixed signal intensity after chemotherapy. Four of the 5 soft tissue sarcoma after preoperative treatment with chemotherapy and radiotherapy also showed iso- or mixed signal intensity. On the water images produced by the 3PD technique, fat appeared darker while the other tissues were brighter. The tumours were detected clearly in all cases with the 3PD technique. On the water images, only the tumour area demonstrated a high signal intensity and on

the fat images only the tumour area had a low signal intensity. The tumour could therefore be localised in this way. With Gd-DTPA enhanced MRI, however, the enhancement was strong in 3 out of 14 cases not only in the tumour area since the reactive and inflammatory area around the tumour was also enhanced.

Case reports

A Ewing's sarcoma of the fifth metacarpal was examined after preoperative chemotherapy by T1-, T2-, and T1-weighted Gd-DTPA enhanced images. On the T1-weighted images, the head of the metacarpal showed iso-signal intensity compared to the fat of the skin (Fig. 1a). On Gd-DTPA enhanced T1-weighted images, the same area was enhanced and showed a high signal, equal to that of fat. It was therefore difficult to identify the tumour area and plan the surgical excision. On the water image, only the tumour area had a high intensity which was easy to depict (Fig. 1b). On fat images, no lipid remained in the bone or around the soft tissues (Fig. 1c) so that a safe surgical margin could be determined.

An osteosarcoma of the tibia was examined by the same procedures after preoperative chemotherapy and showed mixed (iso- and low) signal intensity on the T1-weighted images compared to the intensity of fat (Fig. 2a), and on the Gd-DTPA enhanced T1-weighted images, the peripheral area showed the same high signal as fatty bone marrow (Fig. 2b), so it was difficult to delineate the tumour area. On the 3PD images, the tumour area was clearly depicted and was composed of tissues of a high water content without lipids (Fig. 2c). The MRI findings were proved histologically.

Differential diagnosis

Fat has a very high intensity on T1-weighted images, but a haematoma in the subacute phase may also show a similar high intensity [27]. On water images, fat shows a low signal, while haematoma and fluid demonstrate a high signal intensity, and on fat images only fat demonstrates a

Fig. 1a–c. A girl, 14 years of age, with a Ewing's sarcoma of the fifth metacarpal bone. **a** T1-weighted spin echo (SE) image. **b** Water image. **c** Fat image

Fig. 2a–c. A boy, 16 years of age, with an osteosarcoma of the distal metaphysis of the left tibia. **a** T1-weighted image. **b** Gd-DTPA enhanced T1-weighted SE image. **c** Fat image

Fig. 3a, b. A woman, 40 years of age, with an atypical lipoma in the left shoulder region. **a** T1-weighted SE image. **b** Gd-DTPA enhanced water image

high signal intensity. The 3PD technique is helpful in making the diagnosis from this point of view. Tumours with a high fat content have a high signal intensity and the increase after giving Gd-DTPA is hard to recognise. Whether or not the tumour is enhanced in this way, it is easily detected on water images.

In a lipoma of the shoulder, the signal was high on T1-weighted images, so it was difficult to detect enhancement (Fig. 3a). On water images and enhanced water images, the fat signal was suppressed proving that this tumour contained very little water and showed no enhancement (Fig. 3b). Since lack of Gd-DTPA enhancement was only seen in the enhanced water image, the 3PD technique is useful in this regard.

Discussion

Various types of fat suppression images have been developed to improve radiological diagnosis [3, 12–20]. There are reports of using a short inversion time (T1) inversion recovery image (STIR) method, but problems with the signal to noise

(S/N) ratio and the long scanning times necessary for making the images remained. It was, therefore, difficult to use the method with a 0.5 and a 1.0 T scanner [19–26]. The CHESS method was also difficult to use in a low magnetic field because this requires a powerful homogeneous field to utilise directly the subtle differences of signal between water and lipid [15, 16]. The conventional Dixon technique can be performed with a low magnetic field, but the homogeneity deteriorates and the fat and water decomposition is less accurate. With our modified 3PD method, homogeneity of the imaging was improved and clear images of the tumours in the extremities were obtained.

The T1-weighted images displayed a good contrast between infiltration by tumour and the fatty bone marrow because lipids have a short relaxation time and signal intensities are low in tumours [1]. There are large amounts of lipids in bone marrow. T1-weighted images show no signal loss until oedema is more severe and lipids are displaced by water [1]. If a tumour contains a subacute haematoma with a high concentration of protein, the T1 signal becomes high [27]. On conventional T1- or T2-weighted images, iso- or high signal tumours in bone are difficult to differentiate from surrounding fat. Malignant bone tumours do not always show low signal intensity on T1-weighted images after chemotherapy because most of the tumour is degenerate; the 3PD technique was very useful in these cases.

On T1-weighted images, fat has a very high signal intensity and there are fatty tissues around neurovascular structures. On fat images the remaining fat is easy to detect and if a fat signal is not present around the neurovascular structures they should be excised during operation. On Gd-DTPA enhanced T1-weighted images, the contrast between the tumour and normal bone marrow is not clear because the signal intensity of the tumour area increases to a level equalling the signal intensity of the fat. In tumours which included a lot of lipids or in fatty tissues, contrast between tumour and fat decreases on the conventional T1-weighted images after Gd-DTPA has been given.

Suppression of the lipid signal was possible with 3PD techniques, and after giving Gd-DTPA the enhanced area becomes clearer so that in water images areas with subtle enhancement showed increased intensity; thus 3PD imaging was a very sensitive method of visualising tumours.

Supplementing standard images with Dixon images can provide important additional information for the diagnosis of tumours. Although the time penalty for obtaining 3PD images is twice as

great as that of SE methods and artefacts are sometimes noted, this technique is worthwhile, particularly when performed by a 0.5-T scanner. The 3PD method is therefore useful in evaluating and differentiating tumours of bone and soft tissue.

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