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Musculoskeletal MRI: dedicated systems

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Abstract. The "dedicated" MRI units have characteristics of high diagnostic accuracy and lower installation and management costs as compared with whole-body systems. The dedicated MRI units are easy to install. The low weight allows their installation also under unfavorable circumstances. In a dedicated system cost-effectiveness and ease of installation must be accompanied by the capability of providing high-quality images. In our experience, the high number of examinations performed, the most part of which provided with the surgical controls, allowed an accurate evaluation of the diagnostic potentialities of the dedicated magnet. We were not able to perform the examinations in only 3 % of cases due to the physical shape of the patient and the clinical condition of the patient which may hinder the correct positioning of the limb. The overlapping of the diagnostic accuracy of the E-scan and Artoscan units in the study of the lower limbs, compared with whole-body units and surgery, prompted us to exploit the potentialities of the E-Scan in the study of the shoulder. We had a good correlation between E-Scan, whole-body units, and surgical findings, which confirmed the high diagnostic accuracy of the dedicated system. In conclusion, in our experience carried out in the musculoskeletal system, the dedicated magnets showed promising results. Their diagnostic reliability and utility was comparable to that obtained from conventional units operating at higher magnetic fields.

Key words: Magnetic resonance imaging – Dedicated MRI systems – Musculoskeletal MRI

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Categorical Course ECR 2000

Introduction

Magnetic resonance imaging plays a primary role among the diagnostic imaging modalities. However, high installation and management costs remarkably reduce its use in clinical practice. The study of the musculoskeletal system and, in particular, of joint diseases, can be considered the second field of application of MRI after neuroradiology. On the other hand, the scarcity of MRI units causes whole-body MRI units to be overloaded with diseases of major clinical interest and social importance such as tumors. For these reasons, the use of whole-body MRI in the evaluation of musculoskeletal diseases is very limited.

These considerations have led to the introduction of dedicated MRI systems in diagnostic practice for study of the joints. These "dedicated" MRI units have characteristics of high diagnostic accuracy and lower installation and management costs as compared with whole-body systems [2, 4, 11].

Our experience is based on the technical testing and clinical validation of three dedicated MRI units developed in Italy for the study of upper and lower limbs: the Artoscan Basic (Esaote Biomedica, Genoa, Italy) employed from 1992 to 1997, the Artoscan-M (Esaote Biomedica, Genoa, Italy) employed from 1997, and, the "newborn" E-Scan (Esaote Biomedica, Genoa, Italy) introduced in 1998.

Artoscan Basic and Artoscan-M

Technical and ergonomic considerations

The dedicated MRI units are easy to install. The low weight (Artoscan Basic weighs 1280 kg; Artoscan M weighs 1126 kg.) allows their installation also under unfavorable circumstances. The unit has a built-in radiofrequency (RF) shield that prevents the environmental high-frequency signals from disturbing the signal acquisitions. No need for expensive preparation of the

Table 1. Main differences between Artoscan Basic and Artoscan-M

	Artoscan Basic	Artoscan-M
System layout	One unit, magnet, console, electronics and patient seat are all fixed, not separated	Modular system: magnet and patient seat are separated from the console and electronics unit (default distance = 1.5 m; max. distance = 5 m)
Space requirement	12.25 m^2 (3.5 × 3.5 m)	9 m^2 (2.8 × 3.2 m)
System weight	Magnetic unit/electronic console/patient seat 1000 kg/150 kg/130 kg Total = 1280 kg	Magnetic unit/electronic console/patient seat 960 kg/106 kg/60 kg Total = 1126 kg
Magnet homogeneity	< 50 ppm/90 mm (max.) DSV	< 2 ppm/90 mm (FWHM) DSV < 5 ppm/120 mm (FWHM) DSV
Reconstruction time	1.5 s/image	0.8 s/image visualizing time included
Visualization time	1.3 s/image (512 × 512) 0.4 s/image (256 × 256)	Included
FOV visualized	110 mm	120 mm
MPR preview	Not available	Real-time preview for the 3D data cube

premises results in an additional reduction in the installation costs.

The compact architecture of the system meets specific technical and ergonomic requirements. The small overall dimensions, for example, allow the introduction into the magnet of the sole limb under examination, avoiding uncomfortable positions for the patient, which are difficult to be maintained especially by elderly patients or subjects with acute traumas.

The gantry size is 16 × 34 cm and is shut, at the level of the external holes, by means of a wrap-around curtain which isolates the limb into the magnet from the external influences. The holes are adjusted to the patient limb with closing supports that differ depending on whether the upper or lower limbs are to be examined.

In these units a low magnetic field strength (0.2 T) is accompanied by gradient intensities typical of the high-field units (10 mmT/m).

The dedicated systems are developed and designed taking into account the anatomical region to investigate. In this way the volume of field homogeneity to employ corresponds to the needed one. In our unit, with parity of gradient intensity, the patient is given approximately 10 Amp as compared with 300 Amp given by non-dedicated units. Moreover, the RF excitation is 50 vs 2000 W produced by most of the units currently available. This has a role in the protection of the surrounding environment.

The positioning of the patient for the study of the small joints of the superior limb (elbow, wrist, hand) is performed with the patient seated on a mobile, reclinable armchair with footrest. After extension and 90° abduction of the patient limb, the latter is put close to the gantry. The coil is fastened to a support that, running on grooves built for the purpose, allows correct positioning of the region of interest in the center of the magnet. This kind of coil dedicated to the study of the upper limb is provided with containment pads to avoid involuntary patient motion.

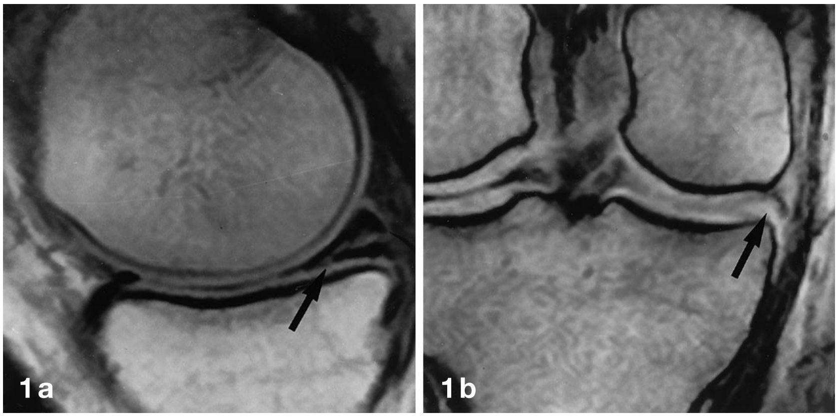
The positioning maneuver to put the region of interest into the coil is performed from outside the unit.

As to the study of the inferior limbs, the patient is half-seated or supine, with divaricate legs. In this way it is possible to introduce into the gantry only the leg under examination. The other leg lies on a support beneath the magnet. For the study of the knee, a standard coil is employed (diameter = 14.5 × 13.5 cm) that, in our experience, allowed the evaluation of 97% of patients. Oversized joints require the use of a bigger coil (diameter = 19 × 14.5 cm). As to the study technique, the optimization of the sequences has allowed for reduction of the examination time. At present time, the study of the joints with this type of magnet on axial, sagittal, and coronal planes lasts 15 min. The standard study technique of the knee includes T1 sagittal spin-echo sequences (5-mm slice thickness), axial turbo multi-echo sequences (4-mm slice thickness) and coronal T2 gradient-echo sequences (5 mm). Depending on the disease, additional sequences can be performed.

The ankle and hindfoot are studied with sagittal T1 SE (5 mm), coronal oblique T2 gradient-echo (5 mm), and turbo-ME or T1 spin-echo axial oblique (4-mm slice thickness) scan planes. A similar study technique is used for study of the forefoot, varying the scan plane inclinations.

The small joints of the upper limbs (elbow, wrist, and hand) are studied following the previously described criteria. However, in most cases, use of a 3-mm slice thickness may be needed. In our experience, the system provided an optimal image quality, with good contrast and excellent spatial resolution (0.4 mm). The signal-to-noise ratio was good even employing 2-mm slice thickness.

The Artoscan-M represents the natural evolution of the Artoscan Basic both from the ergonomic and technological points of view (technological development and update of hard- and software). The main differences between both units are shown in Table 1.



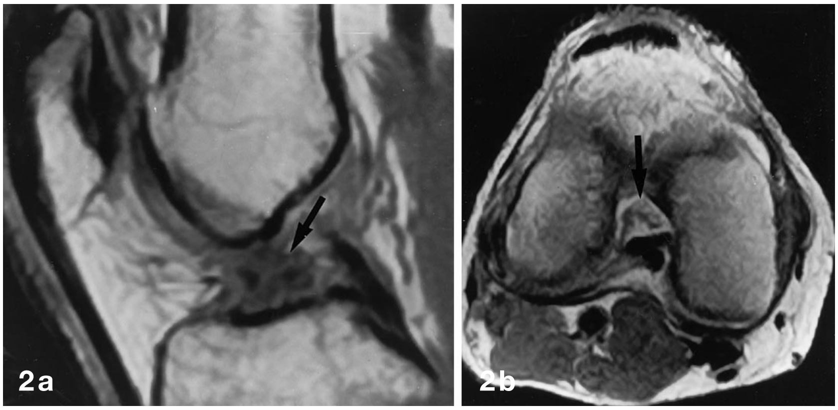


Fig. 1 a, b. Meniscal lesion. **a** MR sagittal T1-weighted spin-echo (SE) scan shows good evidence of posterior horn tear of the medial meniscus *(arrow)*; **b** coronal T2-weighted gradient-echo (GE) scan confirms the meniscal lesion

Fig. 2 a, b. Anterior cruciate ligament (ACL) acute tear. **a** MR sagittal T1-weighted scan shows the ACL acute lesion *(arrow)*; **b** axial T1-weighted scan confirms the lesion of the ACL that appears hyperintense and inhomogeneous *(arrow)*

Clinical considerations

As previously described, in a dedicated system cost-effectiveness and ease of installation must be accompanied by the capability of providing high-quality images. In our experience, the high number of examinations performed, the most part of which provided with the surgical controls, allowed an accurate evaluation of the diagnostic potentialities of the dedicated magnet.

In our institution, the knee accounted for 66 % of the total amount of examinations performed. The following results were achieved: The diagnostic accuracy of the dedicated MR in the study of meniscal lesions was 93 vs 100 % sensitivity and 93 % specificity (Fig. 1). The diagnostic accuracy in the study of ligamentous lesions was 97 % (96 % sensitivity, 99 % specificity; Fig. 2). The lowest accuracy was obtained in the study of cartilaginous lesions (92 %; 82 % sensitivity, 98 % specificity). The lower reliability in identifying the cartilaginous lesions is due to the fact that MRI is not able to identify chondral alterations at an early stage. On the other hand, very high diagnostic accuracy (100 %) was observed in the study of synovial lesions [1, 7].

These results are comparable to those reported in literature using whole-body magnets, even if operating at higher field strengths [5, 6, 9, 10]. For the other articular districts (Fig. 3), fewer examinations were performed, the results of which, however, seem to be comparable to those reported in the literature [3, 8, 12].

There are significant differences between a dedicated MR system and a whole-body unit resulting in technical and logistic advantages and limitations that deserve separate mention. In our experience, we were not able to perform the examinations in 3 % of cases; sometimes, the image quality was so impaired as to prevent us from achieving a correct evaluation of the examinations themselves. Actually, the correct performance or evaluation of an examination can be impaired by two main factors: firstly, the physical shape of the patient; and secondly, the clinical condition of the patient which may hinder the correct positioning of the limb. In our experience, however, these technical limitations were related only to the knee and elbow joints, whereas no problems arose for the study of wrist, hand, foot, and ankle.

The difficulties encountered in the study of the knee were of three types: (a) the knee circumference larger than 42 cm or the thigh circumference larger than 66 cm due to the presence of fatty tissue or marked hypertrophy of the muscles; (b) short thigh related to pediatric age or particular conformation of the patient; (c) severe coxitis (rarely observed) hindering the proper divarication of the legs. The study of the elbow was impaired by the presence of a chronic disease, which did not allow correct positioning of the semiflexed arm into the magnet. On the other hand, the dedicated magnet allowed examination of all patients with acute trauma. This was particularly significant in the athletes, whose investigation during the acute phase is of paramount clinical importance. In these cases, short acquisition sequences (90 s) are sufficient for a correct diagnosis, although they do not have a good signal-to-noise ratio.

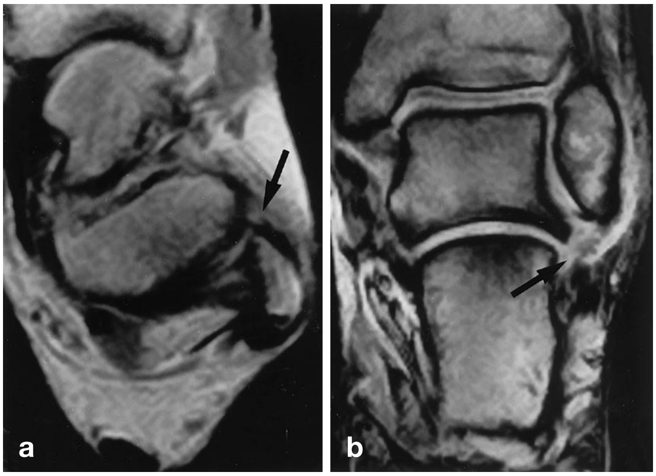


Fig. 3 a, b. Ankle sprain. **a** MR oblique-axial T1-weighted scan shows a lesion of the anterior talofibular ligament *(arrow)* which appears inhomogeneous; **b** MR oblique-coronal T2-weighted GE scan shows the associate lesion of the calcaneo-fibular ligament *(arrow)*

Fig. 4. a E-scan with a specially developed modular radiofrequency shielding and **b** with an integrated RF shielding system

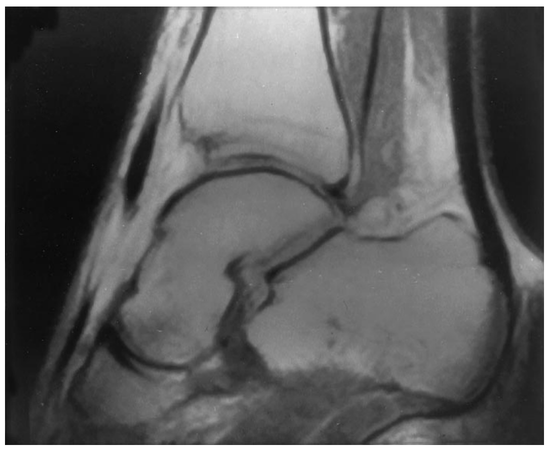


Fig. 5. Anatomical MR sagittal T1-weighted spin-echo scan using 140-mm field of view

Another advantage offered by the dedicated magnet lies in the fact that the patient feels psychologically relieved when introducing into the magnet the sole limb under examination. No claustrophobic reactions were observed in our experience, not even in claustrophobic patients who had not tolerated the examination in a whole-body unit.

The field of view of 11–16 cm allows an accurate investigation of all articular districts, the only limitation being represented by those cases in which a more panoramic view is needed, such as soft tissue or bone neoplastic diseases. The latter, in our opinion, represent the only true limitation to the application of this system.

E-Scan

The high diagnostic accuracy and positive impact on the Italian and world market of the dedicated MRI systems have led to extension of their application also to the study of other articular districts such as shoulder and hip.

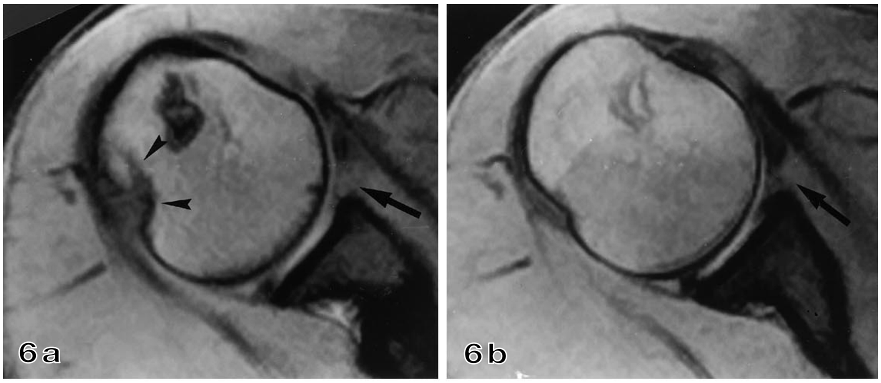
The E-Scan is the result of a long-term development program of Esaote MRI Research Division in collaboration with our department of radiology.

Technical and ergonomic considerations

The E-Scan is the first open dedicated permanent magnet with ergonomic gantry design and vertical magnetic field operating at 0.2 T (Fig. 4). The magnet design is optimized and provides high homogeneity (± 4 ppm over 140 mm DSV, FWHM method). The gradient system has a maximum intensity of 20 mT/m (26 ms) with rise time of 0.8 ms from 0 to 20 mT/m. Its weight is 2.080 kg (1.930 kg for the magnetic unit and 150 kg for the console). As to the stray field, the 5-Gauss line is maximum 130 cm from the magnet isocenter and the 1-Gauss line is maximum 230 cm from the magnet isocenter.

The system is equipped with dual phased-array technology and all coils are provided with a built-in pre-amplifier. The most important characteristics of the E-Scan unit, however, still remain its flexibility, ease of installation, and patient comfort.

The E-Scan has been developed as an "office MRI" which means that it can be easily installed in any hospital or private practice. The minimum space requirements are 15 m^2. There is no need for magnetic shield or expensive premises preparation. An integrated RF shielding system or a specially developed modular RF



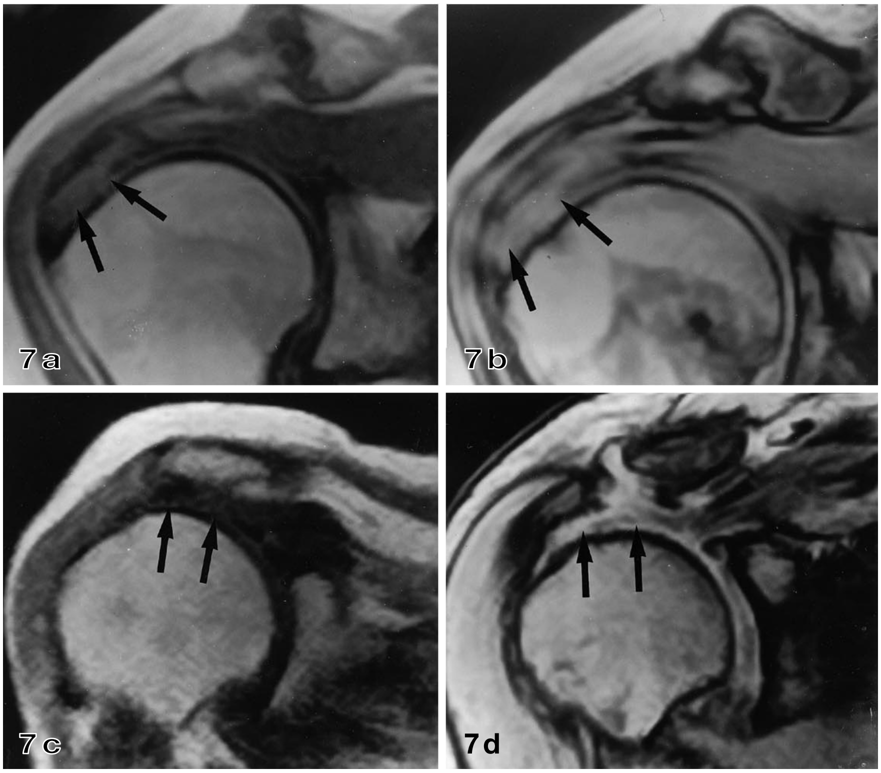


Fig. 6 a, b. Shoulder gleno-humeral instability. MR axial T2-weighted GE scans show a Hill-Sachs lesion of the humeral head *(arrowheads)* and a lesion of the antero-inferior glenoid labrum *(arrows)*

Fig. 7 a–d. Shoulder rotator cuff tear. **a** Supraspinatus tendon tear in acute phase *(arrows)* is evident both on oblique-coronal T1-weighted SE scan plane and on **b** oblique-coronal T2-weighted GE scan plane; chronic rotator cuff complete tear *(arrows)* well shown on **c** MR oblique-coronal T1-weighted SE and **d** T2-weighted GE scan planes

shielding are available. Using the light external RF cage, 18 m^2 (minimum 2.4 m ceiling height) are necessary.

The open design allows patient access from three sides. The main access site has an ergonomic profile with inner opening of 24 cm and outer opening of 30 cm. The design has been optimized to reduce all claustrophobic effects experienced in conventional, whole-body MRI units. The open design also allows the technician or family members to stay in the scan room in close contact with the patient during the examination (traumatized or pediatric patients).

Patient positioning is quite easy. The unique patient table can rotate and shift inside the magnet. The positioning of the patient is performed from outside the magnet. When the setup is completed, the table slides into the magnet and the coil is automatically centered. After patient positioning, a localizer scan (scout) is performed on the three main directions to ensure easy and fast setup of the subsequent scans and to avoid wrong slice positioning.

Clinical considerations

Our clinical approach to the E-Scan has been necessarily different from the one adopted for the Artoscan unit. The ergonomic characteristics and diagnostic accuracy of both dedicated systems in the study of hand, elbow, knee, ankle, and foot were in our experience comparable. The larger gantry and coils offered by the E-Scan allowed the performance of those examinations (in particular of the knee and ankle) that we had not been able to perform with the Artoscan unit, due to particular patient conformation or clinical conditions. Moreover, the larger field of view (140 mm) allowed a better evaluation of some articular structures that the Artoscan was not able to disclose accurately (the quadriceps tendon of the knee and the Achilles' tendon at the level of the ankle; Fig. 5).

The overlapping of the diagnostic accuracy of the E-scan and Artoscan units in the study of the lower limbs, compared with whole-body units and surgery, prompted us to exploit the potentialities of the E-Scan in the study of the shoulder and hip.

Our measure process of the ergonomic and clinical value of the E-Scan unit was carried out in two main phases. From July 1998 to November 1998, we made ergonomic considerations on the unit, to estimate to what percentage the examinations of the shoulder could be performed.

The study of the hip was problematic; therefore, it was temporarily considered a work in progress. The reason is that it requires the separate evaluation of each coxo-femoral joint. In this way the examination time doubles. For the unavailability of a dedicated coil, the one of the shoulder was employed, that due to its size, did not provide good anatomic detail. Of the 20 coxo-femoral joints under examination only 10 (50 %) showed a good anatomic detail. The diagnostic quality of these examinations, however, was satisfying. We therefore believe that in the near future, with the optimization of the coil, it will be possible to have an accurate evaluation also of the hip.

The E-Scan unit has proven to be accurate and reliable in the study of the shoulder. In approximately 100 cases, evaluated from the ergonomic point of view, we obtained good-quality images in 85 % of cases using the integrated RF shielding. This percentage increased to 95 % using the light external RF cage. This was due to the fact that the integrated RF shielding allows the shoulder positioning in two positions alone, whereas with the external RF cage it is possible to rotate the scan table and obtain the best patient positioning into the magnet. The only limitation is represented by the thorax size when it is > 35 cm at the level of the sternum.

The second phase of our evaluation of the E-Scan unit in clinical terms was the most satisfying. We had a good correlation between E-Scan, whole-body units, and surgical findings, which confirmed the high diagnostic accuracy of the dedicated system. The diagnostic accuracy in case of gleno-humeral instability was approximately 90 % (Fig. 6), and in cases of rotator cuff disease it varied between 85 % of partial and 100 % of complete lesions (Fig. 7). Sequence optimization allowed, in our experience, reduction of the examination time. In cases of shoulder instability, in fact, our protocol includes axial T1 SE sequences (4-mm slice thickness), axial T2 GE (4-mm slice thickness) and coronal oblique T1 SE sequences (5-mm slice thickness). In this way the examination time is approximately 20 min. In cases of rotator cuff disease, our protocol includes the employment of coronal oblique T1 SE sequences (5-mm slice thickness), coronal oblique T2 GE (5-mm slice thickness), and sagittal oblique T1 SE sequences (5-mm slice thickness). Also in these cases, the examination time is approximately 20 min.

Conclusion

In conclusion, the dedicated magnets are the result of the current tendency of radiology to be divided into several different diagnostic fields. This leads to the need for the radiologist to superspecialize and become master in one domain.

In our experience carried out in the musculoskeletal system, the dedicated magnets showed promising results. Their diagnostic reliability and utility was comparable to that obtained from conventional units operating at higher magnetic fields.

The good spatial resolution allowed the evaluation of critical districts and small lesions. On the basis of the results obtained, we hope that the use of magnets dedicated to the study of the joints and limbs can be applied also to acute traumatology in emergency suites.

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