# Magnetic Resonance Imaging of Fractures of the Tibia Using Ultrashort TE Pulse Sequences: A Feasibility Study

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**Introduction**: While magnetic resonance (MR) imaging has had considerable success in musculoskeletal studies in general, it has had a very limited role in the study of the pathophysiology of fractures. With conventional clinical sequences normal periosteum and cortical bone display no signal. As a result it has not been possible to characterize these tissues by measuring their MR properties or assessing perfusion within them with contrast agents even though experimental studies using radiolabelled microspheres to measure flow in bone and periosteum have shown marked intra-cortical heterogeneity of cortical blood flow and substantial changes in periosteal blood flow during fracture healing. By using ultrashort TE (UTE) pulse sequences which acquire MR data 20-100 times earlier than conventional pulse sequences it is possible to detect signal from normal cortical bone and periosteum. This approach has allowed the relaxation times of these tissues to be measured and enhancement with contrast agents to be observed (1, 2). We have implemented sequences of this type and performed preliminary studies to assess the feasibility of using them to detect tissue changes in patients with acute fractures of the tibia.

**Subjects and Methods**: Studies were approved by the Institutional Review Board of the Royal Brompton Hospital.
This study has been performed in a University setting in patients with tibial fractures. The MR imaging scans were performed in patients where non-operative treatment in plaster of paris followed by a cast brace was chosen, or where a period in plaster preceded operative internal fixation. Eight patients (6 male, 2 female) aged 22 to 56 years were examined on a total of 14 occasions. Two studies were performed at two days, three at 5-7 days, two at 10-14 days, two at 3-4 weeks and three at 15-16 weeks. These studies were performed during the stage of inflammation (2-7 days), the stage of soft callus (2-4 weeks) and the stage of hard callus (15-16 weeks.) Seven of the patients had fractures of the shafts of both the tibia and fibula. One only had a fracture of the tibial plateau. Two volunteers were also studied. Gadodiamide (0.3 mmol/kg) was administered to one of the volunteers and five of the patients on at least one occasion. The basic pulse sequence employed has been described previously (3). Four sets of images with TEs of 0.08, 5.95, 11.08 and 17.70 ms were obtained including versions with frequency based fat suppression. With each of these sequences difference images formed by subtraction of one of the subsequent echo images from the first were produced. Fields of view of 12 – 35 cm were employed with slice thicknesses of 4-8 mm. Two to eight multiple interleaved slices were obtained. TRs of 500 ms were used with flip angles of 45-80$^{o}$ and slice gaps of 0 - 100% except for serial studies of contrast uptake where the TR was 100 ms (and the acquisition was reduced to 256 steps). All studies were conducted using a birdcage receiver head coil.

**Results:** Images of good quality were obtained with the head coil. This coil allowed single legs to be examined in a plaster cast and was usually large enough to allow the normal limb (not in plaster) to be examined in the coil at the same time. The signal to noise ratio was adequate for detection of signal in cortical bone.Splinting of the fracture with plaster of paris allowed early examination (e.g., two days after injury). However, the presence of a plaster splint around each limb meant that surface coils would have produced a poor performance. Signal was just detectable from the plaster of paris of splint using UTE sequences, but it was not at a significant source of artefact. With follow up studies and patient mobilization, metal components (hinges of a cast brace to allow knee movement) were a source of artefact with the earliest, but particularly later echo images in examining the proximal tibia and fibula. The plaster cast, as well as keeping the fracture in position, ensured repeatable registration of the limb in series studies, but when the plaster was changed, registration was less successful. Furthermore, with resolution of swelling and muscular atrophy, registration of limbs using the plaster cast was less precise since the lower limb became more mobile within the cast. Plaster maintained position before and after contrast administration and within the limits described above, maintaining position for serial studies. The serial studies of uptake continued for up to 40 minutes, and splinting from the cast was useful in maintaining patient position including that of the uninjured limb.

The fracture site was identified in each case as an increase in signal relative to the cortical bone on UTE and conventional sequences. With UTE sequences short T2 components were identified at the fracture site on subtraction images probably due to hemoglobin breakdown products, and in medullary bone, susceptibility effects from bone compression. Fragments of bone were identified. The periosteum was evident with UTE sequences and showed enhancement following fracture in case. Normal periosteum was invisible and indistinguishable from the “no signal” area of cortical bone with conventional sequences. Continuity of periosteum above and below the fracture site was observed on coronal and sagittal images with UTE sequences.
Early fracture healing tissue was usually apparent at the earliest examinations (2-5 days) and had long T2 components. With time shorter T2 components became apparent. The cartilaginous (soft) callus increased in size in the initial follow up studies at 2-4 weeks and consolidated to osseous woven (hard bone) callus at 15-16 weeks. Swelling and local haematoma could be seen at the early stages in muscle adjacent to the site of fracture. This typically resolved on serial studies, and muscle bulk decreased relative to the size of the cast. Tendons, aponeuroses, and muscle sheaths typically showed a high signal on subtracted images on later studies but lower signal if close to the site of injury on initial studies indicating loss of definition and involvement in early fracture healing tissue. In serial studies enhancement of bone, periosteum, and callus increased, substantiating increased perfusion. These components showed different degrees of enhancement particularly on later examinations. Enhancement in short T2 tissues as cartilaginous and early osseous callus could be distinguished from that in long T2 tissues, representing earlier less differentiated fracture healing tissues.

**Discussion:** It was possible to image fractures in early, intermediate, and late stages of healing and to identify fractures and features of the repair process. The initial fracture was probably observable mainly as a result of increased fluid at the fracture site, but UTE sequences also identified short T2 components which may represent clot and other hemoglobin breakdown products. Short T2 components became more apparent over time on UTE difference images. This was probably due to organization, solidification to cartilaginous callus, and ossification. These images evidence that at each point of time a cross section through healing fracture callus shows a multitude of fracture healing tissues, differentiated to a varying degree. The contribution of each tissue might give a significant indication of the healing potential of each fracture. The specific identification of short T2 components was important since these are associated with calcification and ossification, and this may increase over time with organization of callus. Remote effects due to humeral or other circulating factors were potentially observable in the normal limb. This study involved patients with fractures caused by relatively low energy injury who were treated during the course of the study with plaster of paris. The ability to image cortical bone and periosteum, and to study blood flow open up a number of clinical applications. The early assessment of soft tissue injury including damage to the periosteum in high and low energy fractures prior to fixation might be of value in predicting the healing potential of each fracture. At a later time point, the MR sequence might allow a detailed assessment of the patho-physiology of a fracture non-union, study of haemodynamic changes during healing in osteoporosis as well as in the presence of infection.

**References**

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