Does Altered Biomechanics Cause Marrow Edema?1

PURPOSE: To determine if altered weight bearing causes the appearance of marrow edema on magnetic resonance (MR) images.

MATERIALS AND METHODS: Twelve volunteers underwent MR imaging with a short inversion time inversion-recovery (STIR) sequence at 1.5 T. The hips, knees, ankles, and feet were evaluated before and 2 weeks after altered weight bearing achieved with overpronation of one foot. Three volunteers underwent imaging a third time, 2 weeks after overpronation was stopped. Two observers assessed the images for evidence of marrow edema.

RESULTS: Changes were seen on images in 11 volunteers; the overpronated side only was affected in 10. Most changes occurred in the foot followed by the tibia and the femur. Most changes were a diffuse increase in marrow edema. In two volunteers, changes resembled those of stress fractures. The changes were predominant laterally and in the feet and ankles in the sagittal plane and in the feet and ankles in the coronal plane.

CONCLUSION: Altered weight bearing should be added to the list of causes of increased medullary signal intensity (ie, marrow edema) on MR images.

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Figure 1. STIR images (2,500/48/150) of the left tibia in a 29-year-old woman. (a) Image obtained before altered weight bearing shows tibial marrow is hypointense to muscle (arrows). (b) Image obtained 2 weeks after altered weight bearing shows a diffuse change in appearance of tibial marrow to slightly hyperintense to muscle. Subtler changes also are present in the femur.

The femur was affected (one proximally, two distally). Multiple bones were affected in four volunteers (Fig 2). The changes usually consisted of a diffuse increase in marrow edema (nine volunteers), often intense (Fig 1), but occasionally the edema was more subtle (Fig 2). Less frequently, the changes appeared similar to those of stress-type fractures (two volunteers) (Fig 3).

At MR follow-up, in two of the three volunteers, the MR images returned completely to normal, but in the third volunteer, the MR images demonstrated minimal persistent edema. This residual edema was decreased in intensity and was more diffuse (Fig 3). All volunteers were completely asymptomatic immediately after pad removal and at clinical follow-up. Most volunteers, however, described discomfort while wearing the orthotic.

DISCUSSION

Bone is dynamic, undergoing hypertrophy in response to stress (7,8). Alternatively, after immobilization from casting (9) or paralysis (10) or in a gravity-free environment (11), bone atrophy occurs. Remodeling occurs as a response to these changes in stress. Because remodeled bone is known to contain microfractures (12), it may demonstrate abnormal uptake at scintigraphy (13). This physiologic response is associated with pain (14). Although, to our knowledge, marrow changes on T1-weighted MR images have never been proved, conjectures regarding their presence have been made (14). Because remodeled trabecular bone demonstrates both microfractures (12) and medullary edema (15) at histologic examination, not surprisingly we found that the MR imaging appearance of this response often mimicked that of a more diffuse bone bruise. The question arises whether all lesions that fulfill the previously described MR criteria for bone bruise (16,17) are truly traumatic. Since internal derangements cause altered biomechanics, perhaps a fraction of these marrow changes are a response to altered weight bearing.

The MR changes visualized in this study were sometimes similar to those described in stress fractures (18,19). These MR changes may represent the conjectured “stress response” or subclinical stress fracture (14,19). We agree with other prior authors that there is a continuum from physiologic response to stress fracture that represents a relative imbalance or uncoupling between bone resorption and bone formation (16,20). The MR imaging appearance depends on the patient’s place in this continuum. Although it has been stated anecdotally that these changes can be painful, all volunteers in our study were free of symptoms immediately after removal of the pads and at 1-week and 1-month follow-up. In addition, the MR imaging appearance rapidly returned close to baseline. Therefore, although these changes sometimes had the appearance of stress fractures on MR images, they clearly were not fractures clinically.

The major stress in ambulation is on the metatarsals and the calcaneus (10). The load on the metatarsals during ambulation is closer to the stress threshold than that of any other part of the skeleton (21). This explains why the changes were seen most prominently in the feet, in particular, the metatarsals. We found the proximal phalanges to be affected even more frequently than the metatarsals. The explanation for this is overpronation excessively stresses the first ray in the toe-off phase of walking. Marrow changes, often subtle, were also seen in the hips, knees, and ankles.

This study was limited by the relatively small number, small age range,
Figure 3. STIR images (2,100/48/150) in the foot of a 49-year-old woman. The base of the first metatarsal was normal on the baseline image (not shown). (a) Image obtained after altered weight bearing shows a linear region of high signal intensity (arrow) has developed. (b) Image obtained 2 weeks after pad removal shows the marrow edema has diminished and become more diffuse (arrows).

and lack of symptoms of the volunteers. Many changes were subtle and did not occur in all volunteers. Part of this subtlety and lack of universality may be related to suboptimal compliance of the volunteers owing to the discomfort caused by the pads. In addition, the 2-week period selected was relatively arbitrary. Bone remodeling is relatively slow up to 2 weeks and peaks at 6–7 weeks (22,23). Perhaps some changes may have been more obvious after longer periods of altered weight bearing. However, because the pads were uncomfortable, the maximal time for even reasonable compliance was 2 weeks. Another limitation was that no specific relaxation time was obtained, which hindered quantitative analysis. In addition, STIR sequences are somewhat variable in signal intensity characteristics, potentially limiting reproducibility. Magnetic field inhomogeneity also may lead to poor fat suppression with STIR sequences. All these technical difficulties may have added to the subtlety of the changes seen. An additional limitation was that the reviewers were aware of which images were baseline, raising the theoretic possibility of bias in image interpretation. A final limitation was the lack of pathologic proof of our findings. Although we found “marrow edema” to be associated with altered biomechanics, we have no proof of what this MR imaging appearance would represent at histologic examination.

The concept that stress can cause MR imaging alterations, although anecdotally described (16), has not been previously evaluated scientifically, to our knowledge. Increased intramedullary signal intensity is a nonspecific finding. Although increased signal intensity is present in stress fractures and “bone bruises,” our results indicate that increased signal intensity also may be the result of bone response to stress without fracture and even without pain. On the basis of this study, we believe that altered biomechanics should be added to the list of causes of increased intramedullary signal intensity on T2-weighted images.

References