MRI features of post ultrasound diathermy therapy: an unfamiliar entity to radiologists

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Keywords

Musculoskeletal, Bones, Musculoskeletal bone, Musculoskeletal system, MR, Education, Biological effects, Ischaemia / Infarction, Oedema

LEARNING OBJECTIVES

- Review the biophysical effects of diathermy by ultrasound and its therapeutic applicability
- Describe an uncommon complication of therapeutic ultrasound: focal bone marrow abnormalities
- Illustrate the imaging features of this complication with clinical cases, with explanation of it's typical MRI appearance and location, helping to raise awareness among radiologists and orthopedist to this rare entity

BACKGROUND

Diathermy consists in the use of external energy to increase the temperature of deep tissues and has been used with in with therapeutic purposes in musculoskeletal injuries for over 80 years [1]. There are three main forms of diathermy: shortwave, microwave and ultrasound [2].

Ultrasound consists in a high frequency inaudible sound wave that promotes physiological effects on the tissues by means of variable biophysical mechanisms. It can be applied in a continuous manner or with pulsed-waves exposure[1]. Its biological effects are time- and dose-dependent [1] and the average parameters used in published articles on its effectiveness ranged from 1-3MHz (frequency), 0,25-1,5 W/cm2 (intensity) and 2-15min (application time) [1,3]. Higher frequencies (3MHz) can be used in superficial tissues, due to high absorption rate, while lower frequencies (1MHz) are preferred for deep tissue injuries [3,4].

The American Food and Drug Administration department (FDA) suggests that any diathermy device should increase the tissue temperature to up to 104 -114 F at a depth of 2 inches in no more than 20 minutes, not exceeding 3W/cm3, always respecting the pain threshold of the patient [5]. However, systematic reviews show that there is a major variability in the applied parameters [3,6-8].

Event though they occur simultaneously, for educational purposes, the effects on the tissues can be divided in thermal and non-thermal. It is established that non-thermal effects prevails in pulsed-wave ultrasound, since the interval between pulses allow heat dissipation, while thermal effects are more intense in continuous wave mode, in which the average energy is higher [9].

The main non-thermal effect is cavitation, that basically consists in gas bubble formation and its compression/decompression secondary to insonation of the tissues. The sudden expansion and movement of microbubbles may lead to collapse, which can damage cell membrane [1,9,10].

Other non-thermal mechanism is acoustic streaming, in with ultrasound vibration promotes eddies of liquid flow that can alter cell membrane permeability. However, even though proven with in vitro experiments, there is lack of evidence that these mechanisms should occur in vivo, being mechanical damage to cell membrane highly unlikely with therapeutic ranges of insonation [9]. The alleged benefits in cellular and molecular changes, such as blood cell stasis, fibroblasts proliferation, angiogenesis, cell membrane changes and collagen extensibility, have not been proven in clinical studies [9].

The thermal mechanisms depend on several factors, including tissue properties, ultrasound parameters and beam configuration [10]. In clinical practice, the increase in blood flow is limited to the skin and, in order to achieve that hyperemia in deep structures such as muscles and tendons, the intensity of the ultrasound would be intolerable [9,11]. Also, there is no evidence that the heating increases neither cellular or enzymatic activity [9].

As such, even though widely applied in musculoskeletal disorders, the usefulness of therapeutic ultrasound has little supporting evidence. Systematic reviews with randomised controlled trials with multiple pathologies (including painful shoulder, carpal tunnel syndrome, epycondilitis, acute ankle sprains, acute fractures, patellofemoral pain, rheumatoid arthritis) show that the benefits of therapeutic ultrasound are not scientifically supported [3,7,8]. Most studies showed no difference between the placebo and the ultrasound diathermy group; some trials showed improvement of symptoms in both groups, possibly to placebo effect and/or natural healing process [7].

In large trials, no adverse effects have been reported and ultrasound has always been considered a safe physical therapy tool. However, two recent papers showed that this diathermy technique is not without risks and its thermal and non-thermal effects may cause deleterious outcomes in deep tissues, such as adjacent bone structures [2,12].

FINDINGS AND PROCEDURE DETAILS

The bone is a highly acoustic absorbing tissue and is more susceptible to heating when exposed to insonation than the adjacent fat and muscles [11,13,14]. *In vivo* experiments with animals show that the temperature rose 1.8°C in the bone marrow, 4.3°C in the spongy bone, 3.7°C at the bone surface, and 2.2°C in the soft tissue at distances of 1 to 3 cm from the bone after five min of US exposure, as shown in Figure 1 [1,14].

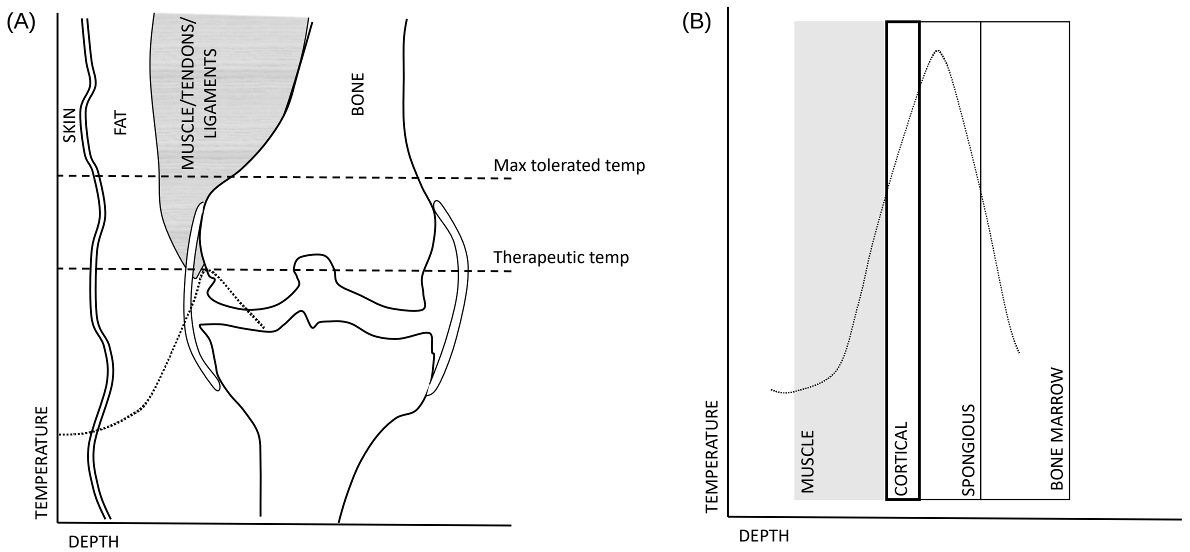

Figure 1. The absorption of the acoustic energy and its conversion to heat is higher at the bone than at the adjacent soft tissues. It means that even if the ultrasound is applied respecting the pain/heat clinical threshold *(i.e.* therapeutic temperature), it may lead to bone injury (A). The rise in temperature is more marked at the subcortical layer of the bone, where cell damage may occur (B).

Most of the acoustic energy that arrives at the bone is absorbed, creating a disk-shaped heated area with an equal size to the ultrasound beam (Figure 2) [12]. The heating of bone structures may lead to cell damage, that can be translated as focal abnormalities at imaging studies. Histologically, this damage is described as empty lacunae and osteocyte necrosis, with sharply demarcated separation between healthy and damaged bone [15].

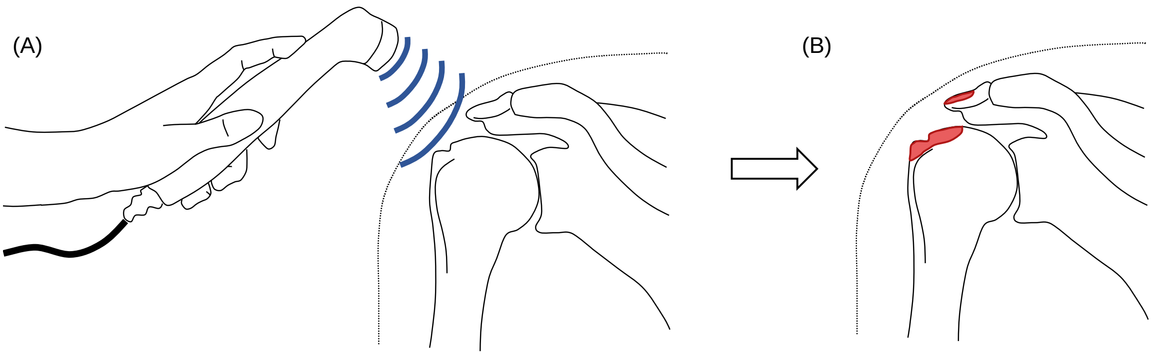

Figure 2. Therapeutic ultrasound is applied over the skin using a coupling gel. The acoustic energy is converted to heat in the tissues, creating a disk-shaped area of increased temperature that may lead to bone injury (A). This thermal damage is represented on imaging studies as osteonecrosis-like lesions at the most superficial surfaces of the bone structures (B).

In 2011, Yeh *et al* published the first cases of focal bone marrow abnormalities as a result of ultrasound diathermy therapy [12]. They reported subcortical bone marrow abnormalities in 8 patients that presented persistent pain after physiotherapy, including four shoulders, four knees (one case of bilateral knee) and one wrist. Most of the insonation parameters were undetermined, but in the three cases in which the information was known, they were in accepted range recommended in the literature.

Kim *et al* reported similar findings in two patients, with pre- and post-ultrasound therapy imaging studies, as well as follow-up MRI [2]. They showed the development of osteonecrosis-like lesions at the superior surfaces of the humeral head and of the acromion in both patients after initiation of diathermy.

The imaging findings of this entity are subcortical rim or arc lesions, with no major changes in deeper aspects of the bone marrow. These lesions present low T1-weighted and high T2-weighted signal in a geographic pattern, resembling areas of osteonecrosis, but are smaller and identified on the bone facing the body surface, usually were the overlying soft tissue is thinner.

On the shoulder, the imaging findings are geographic focal bone abnormalities at the superolateral surface of the humeral head and of the acromion, which are the bone areas closest to body surface at the insonation plan and also where the soft tissue is thinner, as seen in the case of the Figure 3.

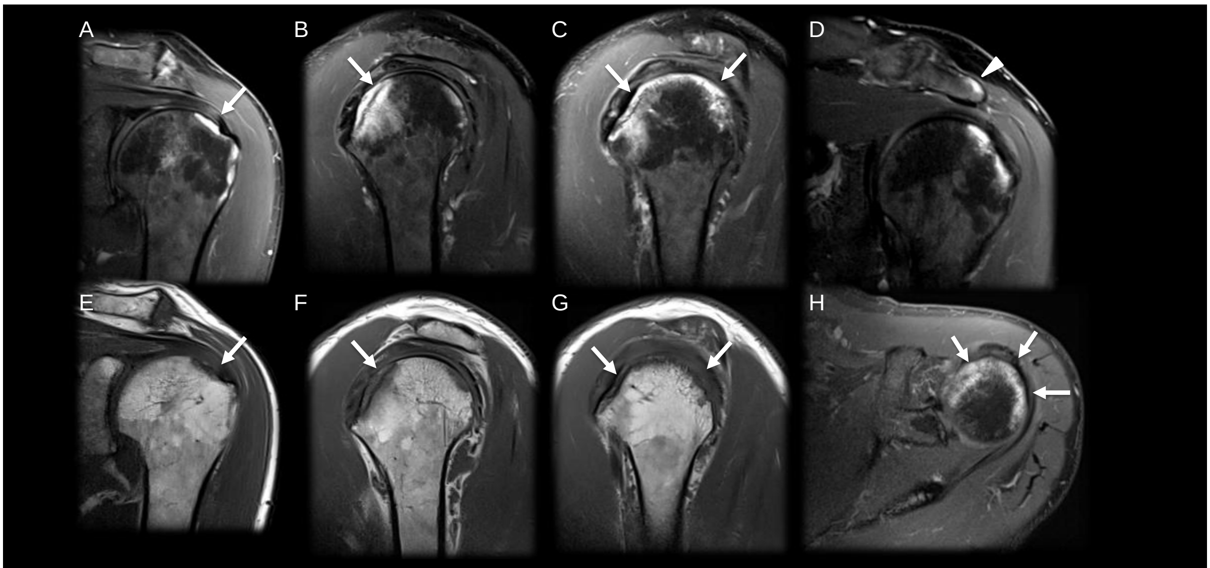

Figure 3. 58 year-old male presenting left shoulder pain for 6 months, with no notion of trauma and preserved range of motion. He underwent physiotherapy treatment 3x per week with ultrasound diathermy, with no improvement of his symptoms. MRI was performed to evaluate the rotator cuff. T2FS (A-D,H) and T1W (E-G) images depict bone marrow abnormalities at the humeral head (arrows), mostly subcortical, with marked delineation of a geographic area at the most superficial surface of the bone. Similar findings were noted at the superolateral surface of the acromion (arrowhead in D). Note that the lesions have a similar imaging appearance as osteonecrosis, but the location is rather unusual. No major rotator cuff lesion was present.

If the ultrasound-related injury happens at the knee, the thermal damage usually occurs at the most external and superficial surface of the distal femur and proximal tibia, depending on which side the insonation was applied (Figures 4 and 5).

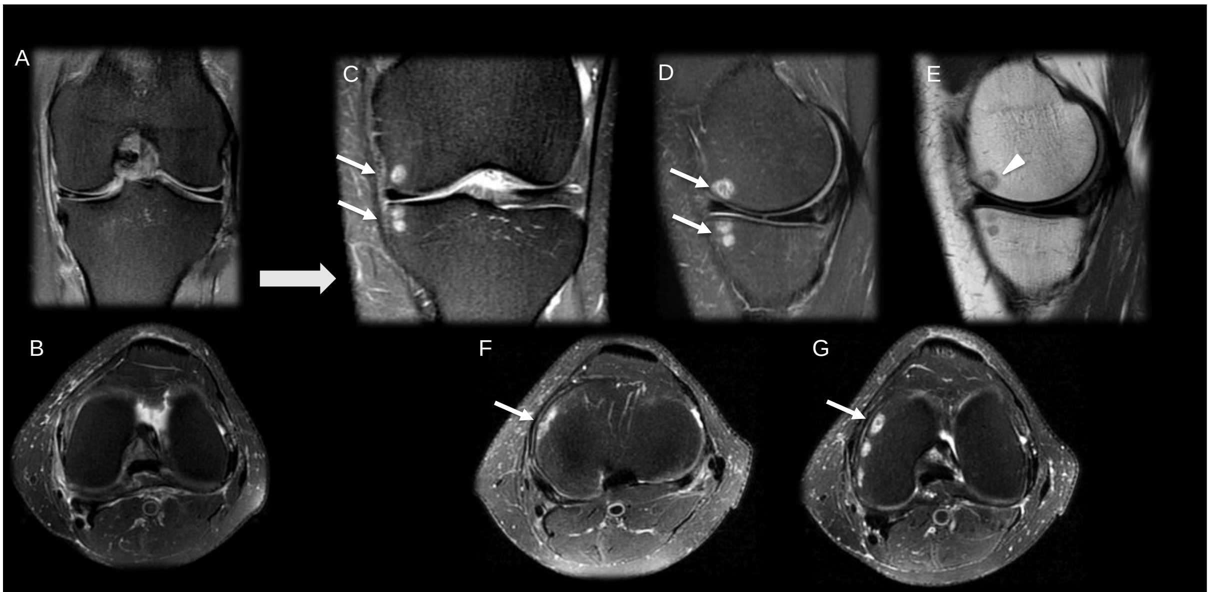

Figure 4. 54 year-old male, presenting medial knee pain and medial meniscal tear at baseline MRI (A and B). Patient was treated with ultrasonic wave diathermy, with persistent pain after 4 months, when a new MRI was performed (C-G). Note the development of focal bone marrow abnormalities at the superficial regions of the medial femoral condyle and tibial plateau (arrows). The lesions are sharply demarcated, with fat in its central regions, resembling a osteonecrosis pattern (arrowhead in E).

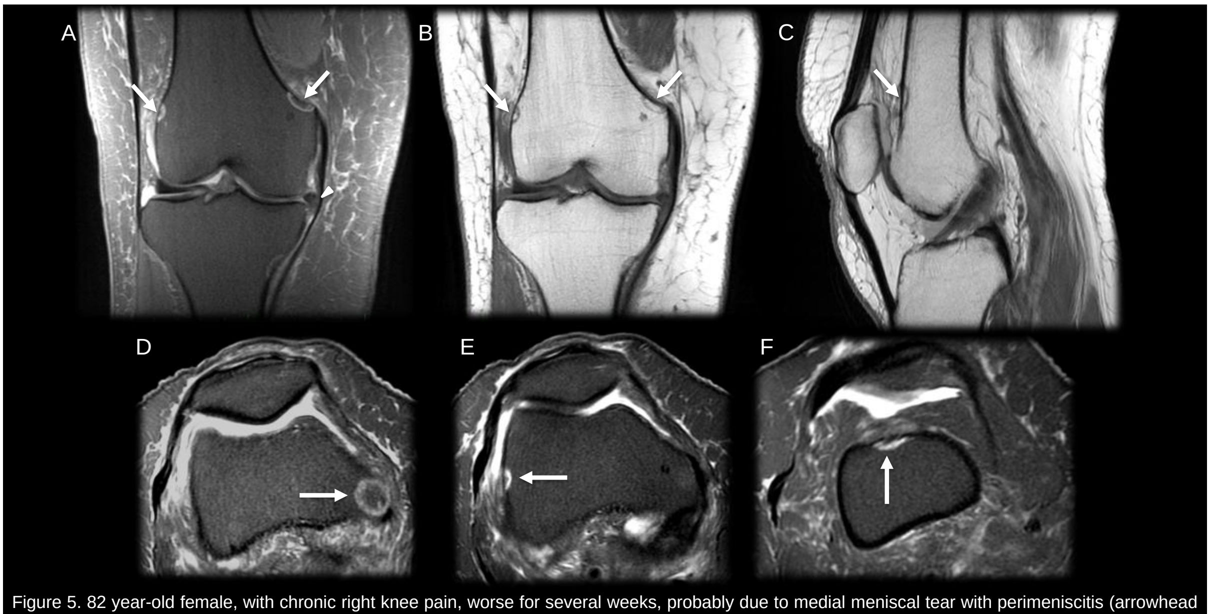

Figure 5. 82 year-old female, with chronic right knee pain, worse for several weeks, probably due to medial meniscal tear with perimeniscitis (arrowhead in A). Patient was under physiotherapy with therapeutic ultrasound. MRI was performed and depicted subcortical bone marrow lesions at the superficial regions of the medial and lateral condyle, as well as anterior femoral metadiaphysis (arrows). The abnormalities are similar to those of the previous cases, represented by osteonecrosis-like lesions at bone areas closer to the body surface.

Not previously reported, we also identified a case of osteonecrosis-like lesion attributed to diathermy on a foot. The patient complained of ankle pain and underwent physiotherapy, with the development of a thermal injury on the basis of the fifth metatarsal bone (Figure 6).

Figure 6. 62 year-old male, runner, complaining of right forefoot pain, in follow-up for long-term metatarsalgia. MRI was performed and showed no bone abnormalities (A and B). He underwent weekly therapeutic ultrasound physiotherapy for two months, with development of pain at the lateral side of the foot. A new MRI was performed 4 months after the first exam (C-F), showing a focal subcortical bone marrow abnormality at the base of the fifth metatarsal (arrows), well delineated, at the lateral superficial surface of the bone. Bone marrow abnormality due to therapeutic ultrasound was hypothesized in correlation with clinical data.

Since there are only few cases reported in the literature, it is not known if these lesions are symptomatic as the patients had preexisting symptoms. Neither we nor the previous case reports applied any comparative assessment on pain.

In all the cases that had follow-up imaging (three cases from Yeh *et al* and both cases from Kim *et al* [2,12], it was noted a complete or near complete resolution of the bone marrow abnormalities on imaging after cessation of the diathermy therapy. The maximal thermal damage usually occurs 2 weeks after the insonation, followed by a healing process from the periosteum and vascular ingrowth from adjacent healthy bone that may require several months [15]. Irreversible osteonecrosis may result from microvascular damage due to acoustic cavitation, which is not likely to occur when safe technique parameters are respected [2].

CONCLUSION

In spite of being a rare entity, given its typical imaging appearance and location, ultrasound diathermy-related bone marrow changes can be recognized by the radiologist, who may help to rule out differential diagnoses and assist the correct management alongside with the attending physician.

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