MRI "road-map" of normal age-related bone marrow

I. Cranial bone and spine

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Abstract. We retrospectively reviewed 733 cranial and 250 spinal T1-weighted MR images of patients younger than 24 years to evaluate the bone marrow changes. The signal intensity of the bone marrow on short-TR/TE images was compared with that of fat and normal muscles in the contiguous region and graded. The signal intensity of all anatomic segments was as low as that of muscle, or inferior, in all patients younger than 3 months because of hematopoietic tissue and probably greater amounts of trabecular bone. The first anatomic segments of cranial bone to become hyperintense were the zygomatic bone and mandibular symphysis, followed by the presphenoid bone, basisphenoid, basiocciput, calvaria, and the petrous apex. After 3 years of age, most patients demonstrated pneumatization of the sphenoid sinus. We describe the most interesting changes in the developing spine, which occur in the first 2 years of life. The morphology of the vertebral bodies was evaluated. The variability of the signal and the morphology of the disks were also evaluated. Regional patterns of bone marrow signal intensity and age-related differences should not be misinterpreted as a pathologic condition.

The bone marrow is the fourth largest organ in the body by weight after bone, muscle, and fat [1]. In the early stages of fetal development, hematopoiesis takes place initially in the liver and, to a lesser extent, in the spleen [2]. Bone marrow begins hematopoiesis in the 4th intruterine month, overtakes the liver in this function by the 6th month, and is fully responsible for red cell production by birth [3].

Cellular marrow constituents include all stages of erythrocytic and leukocytic development, as well as fat and reticulum cells. The basic microstructure of bone marrow consists of a trabecular framework housing fat cells covered with hematopoietic cells, both supported by a system of reticulum cells, nerves, and vascular sinusoids coursing among them [4]. The function of bone marrow is to provide a continual supply of red cells, platelets, and white cells to meet the body’s demands for oxygenation, coagulation, and immunity.

The diversity and complexity of various anatomic, physiologic, and biochemical constituents of bone marrow may be simplified by the unifying concept of a balanced red and yellow marrow distribution. Red marrow is considered hematopoietically active, yellow marrow is considered hematopoietically inactive. The chemical composition of the two types of marrow does differ in important ways. Red marrow contains approximately 40% water, 40% fat, and 20% protein, while yellow marrow contains approximately 15% water, 80% fat, and 5% protein [1]. There are also structural differences between red and yellow marrows in the vascular supply. The rich sinusoidal system of red marrow is replaced by capillaries, venules, and thin-walled veins in fatty marrow. Thus, the vascular network of red marrow can be viewed as being rich and arborized, while that of yellow marrow is sparse [5].

Hematopoiesis is maintained by sequential activation and proliferation of small numbers of hematopoietic stem cells, which ultimately become exhausted and are replaced [6]. During periods of decreased hematopoiesis the fat cells increase in size and number, and during periods of increased hematopoiesis the fat cells atrophy. Reticulum cells, or macrophages, are found predominantly in hematopoietically active marrow [7].

Conversion of red to yellow marrow occurs during growth and development and has a predictable and orderly pattern.

Bone marrow in the neonate is almost entirely red marrow. A progressive conversion to fatty marrow occurs generally from the peripheral (appendicular) toward the central (axial) skeleton. The factors that initiate and modulate this conversion from red to fatty marrow are poorly understood; however, temperature, vascularity, and low oxygen tension may play a role [5].

We reviewed the normal appearance of age-related bone marrow on MR images to obtain a baseline for de-
fining potential bone marrow abnormalities. Once a baseline is established, MRI may be the technique of choice for noninvasive evaluation of bone marrow diseases.

Material and methods

We retrospectively analyzed 733 head and 250 spine MR imaging examinations (528 of males and 455 of females) in patients ranging from 5 days to 25 years. The patients had been imaged for a variety of diseases unrelated to the musculoskeletal and hematopoietic systems. Those with suspected or proved abnormalities involving the skull or bone marrow were excluded. Patients who had systemic disease or who had undergone previous treatment that might affect bone marrow in the skull, such as craniotomy, radiation, or chemotherapy, were also excluded.

Uncooperative children underwent inhalation general anesthesia (isoflurane-enflurane) with continuous monitoring (EKG, pulse oximeter).

All examinations were performed with a superconducting system (Esatom 5000) operating at 0.5 T. Spin-echo (SE) sequence T1-weighted images were obtained with several combinations of repetition time (TR) and echo-delay time (TE). Section thickness was 3–7 mm with 1- to 2-mm intersection gaps. A 256 x 256 matrix was used. Axial and midsagittal planes were evaluated.

To establish the location and appearance of red/yellow marrow in the cranial bone, we analyzed the following segments: presphenoid region, clivus (basisphenoid and basisphenoid), calvarium (occipital, parietal, and frontal), zygomatic bone, mandibular symphysis, and the region of petrous apex. In the case of the spine, the signal intensity and morphology of the vertebral body were evaluated. Cartilage was distinguished from bone marrow on the basis of its expected location as determined with anatomic information, and its signal intensity was compared with that of bone marrow.

The pattern of bone marrow signal intensity was graded from 1 to 3 on the basis of the following criteria: grade 1, uniformly low, low/intermediate signal intensity, approximately isointense or hypointense with respect to muscle (before fatty conversion); grade 2, mixed low, low/intermediate, and high signal intensity; grade 3, almost uniformly high signal intensity, approximately isointense relative to subcutaneous fat. A few loci of low signal intensity may still exist in some examples of grade 3, but in the aggregate they represent a small percentage of the entire marrow space.

In evaluating the presphenoid region, grades 2 and 3 were modified as follows: grade 2, mixed signal intensity or high signal intensity throughout; grade 3, pneumatization detected in addition to grade 2 findings.

Only grades 1 and 3 were assigned to signal intensity in zygomatic bone, mandibular symphysis, and petrous apex because of limited MRI section extension.

Every image was reviewed independently by at least two radiologists.