Pediatric Bone Marrow MR Imaging

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• Bone marrow • MR imaging • Children bone marrow
• Pediatric imaging • Neoplasia

One of the largest organs in the body, bone marrow is highly cellular and the main site of hematopoiesis, producing and regulating the supply of erythrocytes, platelets, and leukocytes.[1] At least some bone marrow is visible in every MR image, underscoring the importance of a good understanding of the MR imaging appearance of normal and abnormal bone marrow. MR imaging is superior to other imaging modalities in the assessment of bone marrow because of its high tissue contrast, especially its sensitivity in detection of fat and water. This unique soft tissue contrast of MR imaging can enable earlier assessment of bone marrow infiltration by tumor or other marrow disorders before osseous destruction becomes apparent on radiograph or CT or metabolic changes occur on bone scintigraphy or positron emission tomography scan.[2]

This article provides an overview of the MR imaging findings in normal marrow and in the most common focal and diffuse marrow lesions encountered in childhood.

NORMAL BONE MARROW

To interpret the MR imaging appearance of marrow accurately it is important first to review the normal constituents of bone marrow and the expected normal developmental and physiologic changes that occur with age.

The development of marrow tissue is dependent on the formation of the marrow cavity and surrounding bone. From the fetal period throughout early childhood, significant osteogenesis is occurring, accompanied by ongoing enlargement of the marrow space.[3] Hematopoiesis starts initially in the fetus in the yolk sac and then extends to the liver and, to a lesser degree, to the spleen by the second trimester.[1,4] In the fourth fetal month hematopoiesis begins within the bone marrow space as bone cavities develop.[1,4] Bone marrow soon becomes the exclusive site of granulocytic and megakaryocytic proliferation; however, it is not until the end of the third trimester that the marrow environment supports erythroblasts. At birth, the bone marrow is the major site of red cell production.[1,4]

On gross examination, bone marrow appears red (hematopoietic marrow) or yellow (fatty marrow) depending on its predominant components. Hematopoietic marrow is red because of the presence of hemoglobin within the erythrocytes and their precursor cells, and is actively involved in hematopoiesis. Fatty marrow is yellow because of its marked lipid content. Fat is a major component of both yellow marrow and (to a lesser extent) red marrow. The amount of fatty marrow is responsive to the need for hematopoietic marrow and can increase or decrease accordingly. When the need for hematopoietic marrow volume increases, as in response to severe blood loss, fatty adventitial cells lose fat and increase the space available for hematopoiesis.[5] During periods of decreased hematopoiesis, fat cells increase in size and number. Fat cells may be actively involved in hematopoiesis, supplying metabolic or nutritional support, possibly along with growth factors.[5] The cellular composition of red marrow consists of 60% hematopoietic cells and 40% adipocytes; its chemical composition is 40% to 60% lipid, 30% to 40% water, and 10% to 20% proteins.[6] In contrast, yellow marrow is almost entirely composed of adipocytes (95%),

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with its chemical composition being 80% lipid, 15% water, and 5% protein.[6,7] Cancellous bone, composed of primary and secondary bridging trabecular bone, provides the underlying structural framework for the cellular elements of marrow and also serves as a mineral depot.[8]

Bone Marrow Conversion

The composition of the cellular marrow changes significantly with age and anatomic location. The rate and patterns of marrow conversion on MR imaging are now well understood and have allowed for the mapping of the expected age-related marrow distribution throughout the skeleton.[9] At birth, hematopoietic marrow is present throughout the entire skeleton. Various regions of hematopoietic marrow then rapidly undergo conversion to fatty marrow with the transition beginning in the periphery of the skeleton in the distal phalanges of the fingers and toes and extending in a symmetric, centripetal manner into the central skeleton (**Fig. 1**).[6,10] The cartilaginous epiphyses and apophyses lack marrow until they ossify. These centers, once ossified, initially contain hematopoietic marrow, followed by rapid conversion to fatty marrow within months of ossification. In the first decade of life, a superimposed additional sequence of marrow conversion begins in the long bones, starting in the diaphyses and progressing toward the metaphyses, particularly the distal metaphyses.[6,10] Persistence of significant hematopoietic marrow in the diaphyses after the first decade of life is abnormal. Prominent hematopoietic marrow in the metaphyses is normal, however, until the end of the second decade of life. Heterogeneous sharply demarcated linear areas or focal islands of red marrow can be encountered as normal variants (**Fig. 2**). Lack of red marrow in the proximal femoral metaphyses in the young child is abnormal and raises concern for myeloid depletion (**Fig. 3**). In the late third decade of life the bone marrow distribution achieves its mature state.[10]

Bone Marrow Reconversion

In the event of increased functional demand for hematopoiesis, yellow marrow may reconvert to red marrow. Conditions triggering reconversion include chronic anemias, such as sickle cell disease and thalassemia; stress; endurance running; obesity; extensive marrow replacement from marrow proliferative or replacement disorders; and chemotherapy with marrow stimulating agents, such as granulocyte colony–stimulating factor (**Figs. 4** and **5**).[9,10] The extent of reconversion depends on the severity and duration of the stimulus. The reconversion process proceeds in the reverse order from initial conversion (ie, from central to peripheral skeleton), and in the long bones from the metaphyses to the diaphyses.[6]

In clinical practice, prominent red marrow can be observed in some areas including in the epiphyses, most commonly in the distal femur, proximal

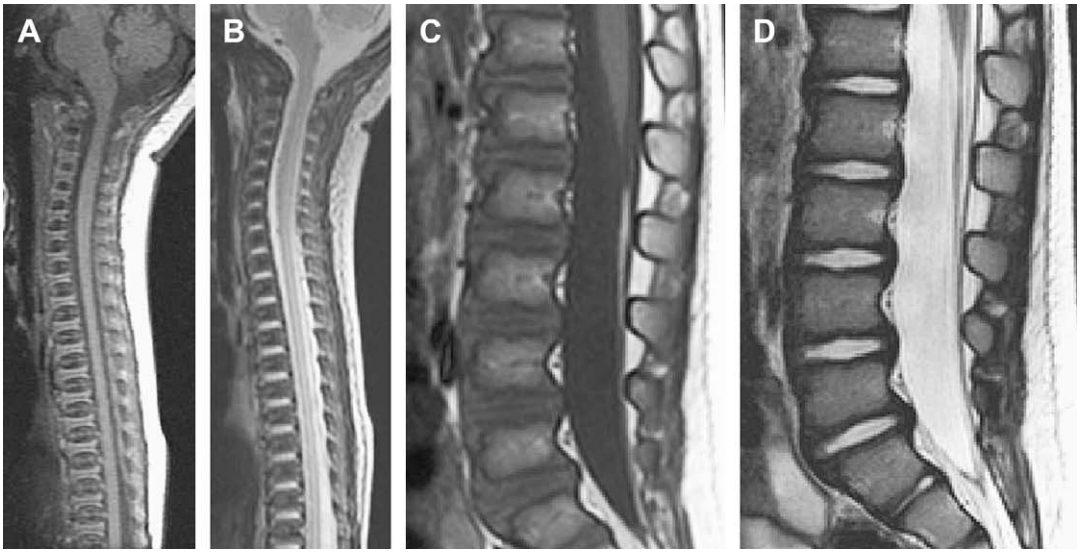

Fig. 1. Normal marrow conversion in the spine. Normal appearance of the upper spine in a 1-day-old baby. Note the appearance on T1-weighted (*A*) and T2-weighted sequence (*B*). Contrast this with the appearance in the lower spine in a 17 month old where there is increased fat present in the vertebrae especially adjacent to the basivertebral vessels on T1-weighted (*C*) and T2-weighted sequences (*D*).