

Age dependent T2 changes of bone marrow in pediatric wrist MRI

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Abstract

Objective Hyperintensity of the bone marrow on fluid-sensitive sequences can be seen on magnetic resonance imaging (MRI) during childhood, even in the absence of bone pathology. They can be related to hematopoietic marrow, normal and abnormal bone remodeling. We sought to investigate whether hyper intensity of the bone marrow on MRI of the wrist is age-dependent and to evaluate if this signal follows a consistent age-related pattern.

Materials and methods Thirty-one wrist 1.5 T MR images of children (7–18 years) without suspected bone pathology were evaluated for foci of hyperintense bone marrow seen on fluid-sensitive coronal sequences using a scale of 1–3. Correlation of frequency, location and intensity of these foci with age was obtained. Results were analyzed for distribution in single bones and in the following regions: distal forearm, first/second carpal rows, and metacarpal bases.

Results A total of 448 bones were evaluated. Eighty-eight out of 448 (21 out of 31 wrists) showed hyperintense bone marrow seen on fluid-sensitive sequences. The distribution was: radius in 19, ulna in 19, first metacarpal base in 11, scaphoid in 9, lunate in 6, pisiform in 6, and fifth metacarpal base in 1. The involvement of the first and second carpal rows and the metacarpal bases was almost

similar (13, 12, and 12 respectively). In the distal forearm, the intensity was similar to or higher than that in the wrist (2.2 vs. 2.0). Frequency decreased with age (100% at 7–9 and 25% at 16–18 years).

Conclusion Foci of hyperintense bone marrow seen on fluid-sensitive sequences can be seen on MRI of the wrist during childhood even without apparent symptoms. It shows a consistent pattern with maturation: frequency and intensity decrease and there is distal-to-proximal resolution. This may be a normal finding that may represent normal bone remodeling or decreasing hematopoietic marrow and should not be confused with pathological bone marrow edema.

Keywords MRI · Wrist · Pediatric · Bone marrow · Children

Introduction

Hyperintense bone marrow seen on fluid-sensitive sequences, frequently termed marrow edema, has disparate causes. In adults, it is usually focal and may have traumatic, inflammatory, infectious, vascular, neoplastic, arthritic, metabolic, iatrogenic, or mechanical etiologies [1–10]. The reason why we notice these regions in adults is that the peripheral skeleton is made up of predominantly fatty marrow. In children, however, there is an evolving mixture of fatty and red marrow that occurs in a predictable and reproducible pattern [11]. In the foot and ankle of children, there is a characteristic, but often disconcerting, pattern of multifocal regions of hyperintense bone marrow seen on fluid-sensitive sequences in the absence of trauma, which may be attributed to altered biomechanics related to growth and weight-bearing or islands of hematopoietic marrow [12]. Consequently, we sought to discern if a similar

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process of age-related marrow hyperintensity seen on fluid-sensitive sequences occurs in the upper extremity, specifically around the wrist. The wrist is an interesting joint to study as it is not weight-bearing.

Materials and methods

Thirty-one magnetic resonance imaging (MRI) studies of the wrists performed at 1.5 Tesla were included in this study. The patients were identified from a RIS database search for MRI studies of the wrist in patients up to 18 years old performed at our department over a period of 6 years. We selected only the patients who had no history of significant trauma, bone neoplasm, arthropathy or infection and for whom there were MRI studies that had both a coronal T1 and a coronal fluid-sensitive sequence, either inversion recovery or fat-suppressed T2-weighted images. From this group, we included only patients with normal bone marrow signal on T1-weighted images. Normal signal on T1 was considered when the marrow signal was brighter than that of muscle. The study group included 21 females and 10 males (mean age 13.2 years, range 7–18). Approval from our Institutional Review Board was obtained for this retrospective chart and report review without the requirement for individual informed consent.

Sequences included coronal T2 fat-suppressed fast spin echo sequences (TR/TE=30,00–3,500/90) in 30 wrists and inversion recovery in 1 wrist (TR/TE/TI=3,500/45/150). The MRIs were obtained with a field of view of 10 cm, and section thickness was 3 mm with a 1-mm gap. A wrist coil was used for all but one case. Two fellowship trained musculoskeletal radiologists who were blinded to the patient's age and clinical history retrospectively evaluated the selected images by consensus for hyperintense bone marrow seen on fluid-sensitive sequences.

Evaluated bones were: distal radius, distal ulna, carpal bones and bases of the metacarpals. Each carpal bone and metacarpal base was considered as one location. The distal radius and ulna were divided into the epiphysis and metaphysis, which were considered as separate locations (two locations in the distal radius and two in the distal ulna). Then we divided the wrists into regions as follows: distal forearm, first carpal row, second carpal row, and base of the metacarpals. We did this as the progression of marrow evolution has been described as occurring in distal to proximal direction.

When high-signal marrow was present, the hyperintensity was graded on a scale from 1 to 3: 1 = mild, barely visible, 2 = moderate, visible but notably less than for fluid, and 3 = marked, approaching fluid in intensity.

Because of the small numbers, the patients were coalesced into the age groups 7–9 years (four wrists), 10–

11 years (three wrists), 12–13 years (ten wrists), 14 years (four wrists), 15 years (two wrists), and 16–18 years (eight wrists). The frequency and the location of hyperintense bone marrow seen on fluid-sensitive sequences and the intensity of those units and regions were compared among the age groups.

The average grade of hyperintensity for each location or region was calculated and correlated with age as follows. For each patient we averaged the grade of hyperintensity of the positive locations/regions. We then examined the average signal intensity for each age group.

One patient had a sequential study of the same wrist after 17 months. We noted the interval changes.

Results

A total of 448 locations were evaluated in the 31 wrists studied. Eighty-eight out of 448 (20%) locations (22 out of 31 wrists) had foci of hyperintense bone marrow seen on fluid-sensitive sequences (Fig. 1). The most common locations of hyperintense bone marrow seen on fluid-sensitive sequences were the radius (19 wrists, 6.1%) and ulna (19 wrists, 6.1%), the base of the first metacarpal bone (11 wrists, 5.8%), the scaphoid (9 wrists, 4.7%), the lunate and pisiform (6 wrists, 3.2%), the capitate (4 wrists, 2.1%), the triquetrum and trapezoid (3 wrists, 1.6%), and the hamate and trapezium (2 wrists, 1.0%). The least common location was the base of the fifth metacarpal bone (1, 0.9%; Fig. 2).



Fig. 1 A 12-year-old boy with hyperintense bone marrow seen on fluid-sensitive MR sequences in the scaphoid (white arrow), lunate (open arrow), the triquetrum (black arrow), and the base of the first metacarpal bone (white arrowhead) (3,000/65)

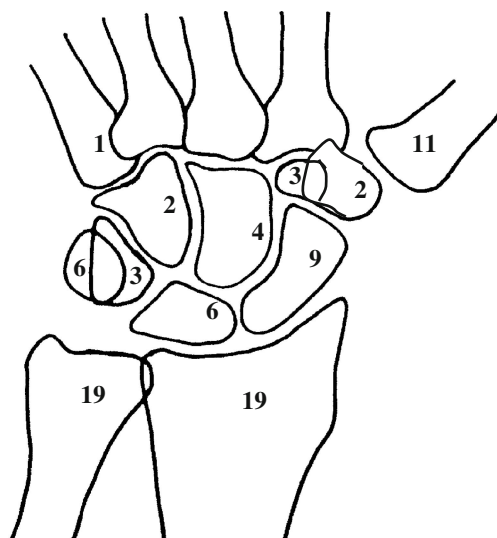


Fig. 2 The frequency of hyperintense bone marrow seen on fluid-sensitive sequences in the various bones. These were mostly seen in the distal radius and ulna and were least detected at the base of the fifth metacarpal bone

Analysis of regions

The distal forearm had hyperintense bone marrow seen on fluid-sensitive sequences (20 wrists, 71%) more frequently than the first carpal row (13 wrists, 41%), the second carpal row (12 wrists, 39%) or the bases of the metacarpals (12 wrists, 39%; Fig. 3). In 4 wrists, foci of hyperintense bone marrow seen on fluid-sensitive sequences were seen in the distal radius and/or ulna, but not in the carpus. In only one wrist was hyperintense bone marrow seen on fluid-sensitive sequences present in the carpus (capitate), without hyperintense bone marrow seen on fluid-sensitive sequences in the forearm. None of the 19 wrists with radial hyperintense marrow, but 3 out of 19 with hyperintense marrow in the ulna showed epiphyseal involvement. These three were in the 11- to 12-year age group. Two of them showed involvement of the metaphysis as well.

Age–location correlation

The 7- to 9-year (4 wrists) and the 10- to 11-year (3 wrists) age groups all had hyperintense bone marrow seen on fluid-sensitive sequences. The frequency in the 12- to 13-year age group was 90% (9 out of 10), and it was 75% (3 out of 4) in the 14-year age group, 50% (1 out of 2) in the 15-year group, and 25% (2 out of 8) in the 16- to 18-year age group (Table 1). Hyperintense bone marrow seen on fluid-sensitive sequences was seen up to age 12 in the ulnar epiphysis and triquetrum, up to 14 years in the radial metaphysis, trapezium, and trapezoid, up to 13 years in the scaphoid, up to 15 in the lunate, capitate, pisiform, hamate, and metacarpals, and up to 17 in the ulna metaphysis.

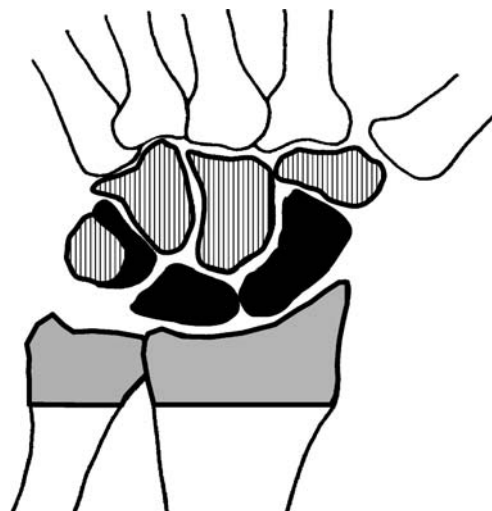


Fig. 3 The frequency of hyperintense bone marrow seen on fluid-sensitive sequences by location: distal radius and ulna (gray, 20 wrists), first carpal row (black, 13 wrists), second carpal row (stripes, 12 wrists), and bases of the metacarpal bones (white, 12 wrists)

Age–intensity correlation

In the 7- to 9-year age group the average grade of signal intensity was 2.0 in 3 wrists and 3.0 in 1. The signal intensity was fairly homogeneous within each wrist. In the 10- to 11-year age group one examination showed grade 3 hyperintense bone marrow seen on fluid-sensitive sequences in the distal forearm and grade 1 in the lunate and pisiform, with an average signal intensity grade of 2.0. The other patient had grade 1 marrow hyperintensity in the distal radius, grade 2 in the distal ulna, and grade 2 in the metacarpal bases, with an average grade of all the locations of 2.5 and an overall average grade of signal intensity of 2.2. In the 12- to 13-year age group the average grade of signal intensity was 2.2. The average grade of signal intensity was 1.7 in the 14-year, 2.2 in the 15-year, and 1.5 in the 16- to 18-year age groups.

Table 1 Frequency and average grade of signal intensity of the hyperintense bone marrow seen on fluid sensitive sequences by age

Age group	Frequency of hyperintense bone marrow on fluid sensitive sequences	Average grade of signal intensity (1–3)
7–9	100% (4/4)	2.2
10–11	100% (3/3)	2.2
12–13	90% (9/10)	2.2
14	75% (3/4)	1.7
15	50% (1/2)	2.2
16–18	25% (2/8)	1.5

Location–intensity correlation

The average grade of hyperintense bone marrow seen on fluid-sensitive sequences, which was highest at the distal forearm (2.3) and lowest at the trapezium (1.5) and metacarpal bases (1.8), and the average grade of hyperintense bone marrow seen on fluid-sensitive sequences in the various locations are as demonstrated in (Fig. 4)

One patient had undergone two examinations, the first at age 12 and the second at 14 (with a 19-month interval). The initial MRI examination demonstrated hyperintense bone marrow seen on fluid-sensitive sequences at the radial and ulnar metaphysis, lunate, triquetrum and the base of the fifth metacarpal bone. Although there was still some distal radial and ulnar metaphyseal hyperintense bone marrow seen on fluid-sensitive sequences visible on the second MRI, the intensity had decreased from grade 2 to 1. The carpal bones and bases of the metacarpal bones showed complete resolution (Fig. 5).

Discussion

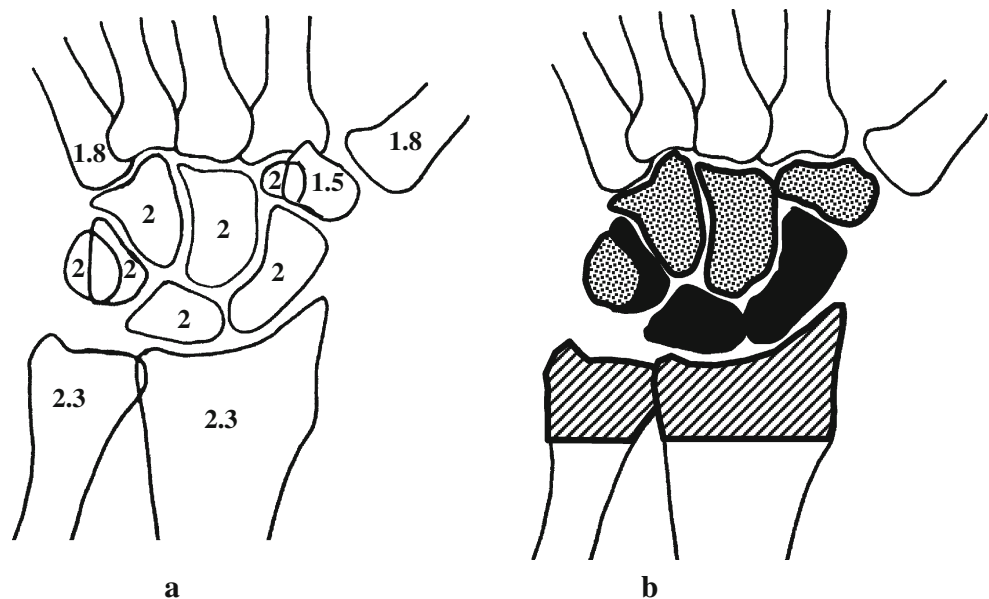
In children high signal of the bone marrow on T2WI and short T1 inversion recovery (STIR) sequences can be caused by various pathological conditions such as stress injuries, acute traumatic injuries, infection, and tumors [1–10]. Hyperintensity on fluid-sensitive sequences can also represent hematopoietic marrow [9] and can also be normally seen around the physis [11]. On T1-weighted images, hematopoietic marrow is intermediate to low [9], but higher than muscle [9, 13–15] in signal intensity. Red marrow, among a number of other processes can look quite

edematous on T2WI. Several other physiological causes of hyperintense signal on fluid-sensitive sequences have been described including normal physal growth, the zone of provisional calcification, endochondral growth, and growth recovery lines [11]. As the round bones of the wrist are considered as epiphysis (ossification centers), high signal in these bones can also represent vascular channels (Fig. 4) [11]. Thus, in children, in whom hematopoietic marrow is not infrequently seen, differentiating between pathological and physiological causes of hyperintense bone marrow seen on fluid-sensitive sequences can be challenging.

In our study we found a pattern of hyperintense bone marrow seen on fluid-sensitive sequences of the wrists that consistently resolved during maturation, in a distal to proximal direction. This pattern is quite similar to that of normal marrow conversion, as described by Neumann (1882) [16], Pinney 1922 [17], and Custer and Ahlfeldt (1932) [18]. The marrow in the newborn is mostly hematopoietic [9, 17, 19, 20] while it is mostly fatty after the first two decades. Generally, the marrow converts in a distal to proximal direction. In the terminal phalanges it begins just before birth and is complete by the age of 1 year [9, 17]. By the age of 5 years, the marrow conversion in the hand is complete and with residual red marrow in the distal forearm metaphyses. The marrow conversion of the metaphysis is completed by the age of 15 years [13].

The conversion on MRI of the wrists has been previously described by Taccone et al. based on T1-weighted images only [13]. On MRI of the foot, hyperintense bone marrow seen on fluid-sensitive sequences is normally seen up to the age of 16 and gradually decreases with age [12]. In the current study, we found a similar pattern in the wrist: the frequency of hyperintense bone

Fig. 4 Location–intensity correlation. **a** The average intensity of the locations. **b** In a distal to proximal direction the average intensity is higher: metacarpal bases (*white*): 1.8; second carpal row (*dots*): 2; first carpal row (*black*): 2; distal forearm (*stripes*) 2.2



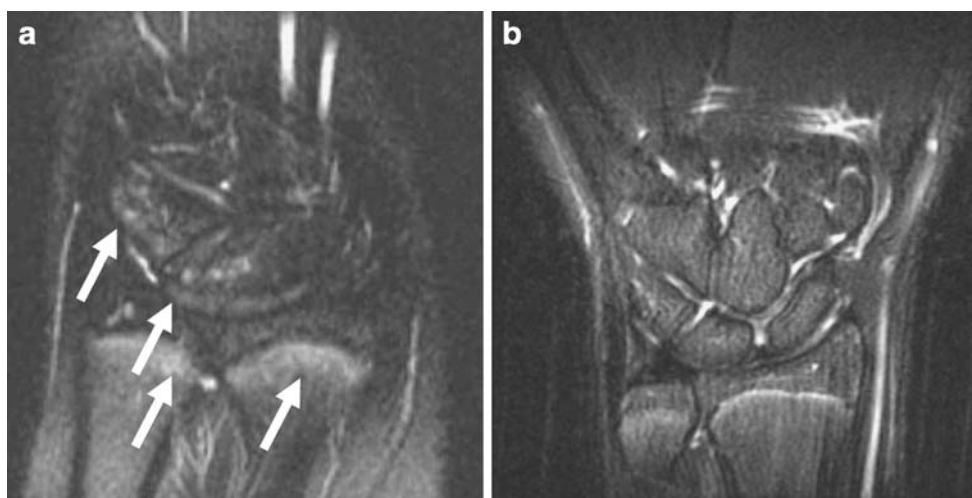


Fig. 5 Interval resolution of hyperintense bone marrow seen on fluid-sensitive sequences in the wrist. **a** At 12 years of age: regions of hyperintense bone marrow seen on fluid-sensitive sequences of the bone marrow are seen at the distal radius and ulna (*arrows*), representing the normal appearance of the metaphysis, and in the lunate and triquetrum (grade 3), possibly representing normal

occurrence of vessels in the carpal bones. **b** At 14 years of age: only residual hyperintense changes of the bone marrow are seen in the distal forearm. The hyperintense bone marrow seen on fluid-sensitive sequences of the other bones has disappeared. Note that the intensity of the hyperintense bone marrow seen on fluid-sensitive sequences in the distal forearm has decreased

marrow seen on fluid-sensitive sequences was seen more often under the age of 14 years and in only 1 out of 8 wrists after the age of 16 years. The intensity of the hyperintense bone marrow seen on fluid-sensitive sequences also decreased with age. In addition, one sequential study on the same patient showed partial resolution and reduction in the intensity of the remaining hyperintense bone marrow seen on fluid-sensitive sequences. This single case is interesting because it follows the consistent pattern of disappearance of this signal with age.

The results of our study coincide with Babyn et al.'s description of the pattern of hematopoietic to fatty marrow conversion with gradual disappearance of red marrow [9]. We found distal to proximal resolution, similar to the pattern that is described in feet MRI and similar to the known histological pattern of marrow conversion in the wrist. At the age of 15 years and older all but one of our patients had residual hyperintense bone marrow seen on fluid-sensitive sequences in the distal radial metaphysis, the most proximal location we studied.

Our current study concentrated on fluid-sensitive sequences, mainly fat-suppressed T2 FSE, as we have encountered visible high signal changes on these sequences that posed a clinical problem in children. It is possible that the fluid-sensitive sequences are more sensitive for visualization of red marrow, explaining the variation between our results and those of Taccone et al. [13]. Another etiology for normal hyperintense bone marrow seen on fluid-sensitive sequences is the physis. The round bones of the carpus follow a pattern of maturation similar to a secondary ossification center, with high signal at the periphery. We are aware that in the

distal forearm, we also counted the linear normal high signal of the presumed normal vascularity of the physis. The differential diagnosis for these areas of hyperintense fluid-sensitive sequences of the bone marrow, especially in children without notable stress injuries, acute traumatic injuries, infection, inflammation, and tumors is narrow. Tumors are very uncommon at this location, especially in the pediatric population, and infection has a fairly overt clinical presentation.

We feel it important to emphasize that, unlike the foot and ankle, the wrist and hand do not have gravitational effects such as altered mechanics, or abnormal bone remodeling. This is supported by the relative infrequency of stress fractures in the upper extremity [21]. Therefore, in some ways the wrist is a cleaner model to study physiological but non-weight bearing effects.

The results of the current work should be weighed against consideration of a number of study design limitations, especially the small numbers of patients and the lack of pathological correlation. Ethical restraints, however, preclude biopsying these patients and cadavers of children are difficult to acquire. Moreover, specimens from amputated wrists are rare, and those that are available are often compromised by disease and treatment. Also, we relied on the clinical history as it was given on the patients' referral slip, which was not always detailed. We acknowledge that a prospective, especially longitudinal study is the best way to address these limitations.

In conclusion, a consistent pattern of age-dependent hyperintense bone marrow seen on fluid-sensitive sequences is seen on pediatric wrist MRI. It gradually disappears in a

distal to proximal direction during maturation, and possibly represents a combination of hematopoietic marrow and normal growth. Recognition of these patterns may aid in differentiating between normal and pathological conditions.

References

- Schweitzer ME, White LM. Does altered biomechanics cause bone marrow edema? *Radiology* 1996;198:851–3.
- Robertson PL, Schweitzer ME, Bartolozzi AR, Ugoni A. Anterior cruciate ligament tears: evaluation of multiple signs with MR imaging. *Radiology* 1994;193:828–34.
- Hayes CW, Conway WF, Daniel WW. MR imaging of bone marrow edema pattern: transient osteoporosis, transient bone marrow edema syndrome, or osteonecrosis. *RadioGraphics* 1993;13:1001–11.
- Papadopoulos EC, Papagelopoulos PJ, Boscainos PJ, Paschaloglou D, Gandaifis ND. Bone marrow edema syndrome. *Orthopedics* 2001;24:69–73.
- Vande Berg BE, Malghem JJ, Labaisse MA, Noel HM, Maldague BE. MR imaging of avascular necrosis and transient marrow edema of the femoral head. *RadioGraphics* 1993;13:501–20.
- Kroon HM, Bloem JL, Holscher HC, Kroon HM, Bloem JL, Holscher HC. MRI of edema accompanying benign and malignant bone tumors. *Skeletal Radiol*. 1994;23:261–9.
- Morrison WB, Schweitzer ME, Bock GW, Mitchell DG, Hume EL. Diagnosis of osteomyelitis: utility of fat-suppressed contrast-enhanced MR imaging. *Radiology* 1993;189:251–7.
- Morrison WB, Carrino JA, Schweitzer ME, Sanders TG, Raiken DP, Johnson CE. Subtendinous bone marrow edema patterns on MR images of the ankle: association with symptoms and tendinopathy. *AJR Am J Roentgenol*. 2001;176:1149–54.
- Babyn PS, Ranson M, McCarville ME. Normal bone marrow: signal characteristics and fatty conversion. *Magn Reson Imaging Clin N Am*. 1998;6:473–95.
- Jurriaans E, Singh NP, Finlay K, Friedman L. Imaging of chronic recurrent multifocal osteomyelitis. *Radiol Clin North Am*. 2001;39:305–27.
- Laor T, Jaramillo D. MR imaging insights into skeletal maturation: what is normal? *Radiology* 2009;250(1):28–38.
- Shabshin N, Schweitzer ME, Morrison WB, Carrino JA, Keller MS, Grissom LE. High-signal T2 changes of the bone marrow of the foot and ankle in children: red marrow or traumatic changes? *Pediatr Radiol*. 2006;36:670–6.
- Taccone A, Oddone M, Dell'Acqua AD, Occhi M, Ciccone MA. MRI “roadmap” of normal age related bone marrow. II. Thorax and extremities. *Pediatr Radiol*. 1995;25:588–95.
- Emery JL, Follett GF. Regression of bone-marrow haemopoiesis from the terminal digits in the foetus and infant. *Br J Haematol*. 1964;10:485–9.
- Foster K, Chapman S, Johnson K. MRI of the marrow in the paediatric skeleton. *Clin Radiol*. 2004;58:651–73.
- Neumann E. Das Gesetz der Verbreitung des gelben und roten Markes in den Extremitätenknochen. *Centralbl Med Wiss*. 1882;20:321–3.
- Pinney A. The anatomy of the bone marrow. *BMJ*. 1922;2:792–5.
- Custer RP, Ahlfeldt FE. Studies on the structure and function of bone marrow. II. Variations in cellularity in the various bones with advancing years of life and their relative response to stimuli. *J Lab Clin Med*. 1932;17:960–2.
- Custer RP. Symposium on hematology. Studies on the structure and function of bone marrow. I. Variability of the hematopoietic pattern and consideration of method for examination. *J Lab Clin Med*. 1932;17:951–9.
- Vogler JB, Murphy WA. Bone marrow imaging. *Radiology*. 1988;168:679–93.
- Schweitzer ME, Haims AM, Morrison WB. MR imaging of ankle marrow. *Foot Ankle Clin*. 2000;5:63–82.