Pediatr Radiol (1993) 23: 515–518

Pediatric Radiology

Pediatric spinal bone marrow: assessment of normal age-related changes in the MRI appearance

G. H. Sebag[1], J. Dubois[2], M. Tabet[1], A. Bonato[1], D. Lallemand[1]

[1] Hôpital des Enfants-Malades, 149 rue de Sèvres, F-75015 Paris, France
[2] Hôpital Ste-Justine, 3175 Chemin Ste-Catherine, H3T 1C5 Montreal, Quebec, Canada

Received: 20 May 1993/Accepted: 28 July 1993

Abstract. A retrospective study of 100 children (0–15 years) without known bone marrow abnormality, was performed to elucidate the spectrum of the MRI appearance of spinal bone marrow with age on T1-weighted images at 0.5 T. Fatty marrow distribution and vertebral signal intensity (SI) relative to disk SI were noted in each subject, and allowed the identification of distinctive patterns. The spinal marrow patterns and their relative frequency for different age groups were consistent with the known physiologic conversion from cellular to fatty marrow with age. Between the ages of 0 and 1 year, SI of corporeal ossification centers was similar or lower than SI of adjacent cartilage and disk in 87% of cases. Between the ages of 5 and 15 years, vertebral SI was higher than SI of adjacent disks in 90% of cases. A central or basivertebral zone of high SI consistent with focal fatty marrow was found in 16% and 31% of cases respectively. In conclusion, knowledge of these conversion patterns should serve as a practical aid in the interpretation of MRI examinations of the spine in children.

At birth, all the vertebral bone marrow is hematopoietic. There is a slow increase in the fat content of spinal marrow with age, known as the phenomenon of marrow conversion [1–3]. Only with a knowledge of the normal conversion patterns can pathologic changes be ascertained. Since the MRI signal intensity (SI) in vertebral marrow reflects a weighted average of relatively short T1 fat and long T1 water, conversion patterns can be assessed with the use of T1-weighted spin-echo (SE) sequences.

The previously described age-related changes in SI of normal vertebral body marrow have generally been the result of work on cadavers [4, 5], adults [6–8] or infants [9], and studies have included no or few children. The aim of this retrospective study was to identify the major conversion patterns of lumbar spinal marrow with age on T1-weighted images in children and therefore to provide a practical aid to the visual interpretation of MRI examinations of normal and abnormal spinal marrow.

Correspondence to: G. Sebag

Patients and methods

The authors retrospectively evaluated 100 MRI examinations of the lumbar spine in 100 children without known bone marrow abnormality who ranged in age from 1 month to 15 years. There were 52 males and 48 females (sex ratio 53%). Demographic data are shown in Fig. 1. We excluded patients with known bone marrow disease, malignancy, focal lesions including neoplasm, infection, trauma, disk disease and prolonged immobilization, and those with a history of corticosteroid treatment, radiation therapy or chemotherapy.

Sagittal and/or coronal T1-weighted SE images were obtained with use of a surface coil on a 0.5 T unit (Magniscan CGR, Buc, France). The technical parameters for all studies were: TR/TE 400–650/21–26 ms, 192 × 256 matrix, two or four signals averaged, 10% interslice interval and a 4–5 mm slice thickness.

The signal intensity of vertebral bone marrow relative to that of adjacent disk was evaluated and graded as lower, equal or higher. The presence and the distribution of focal areas of high SI consistent with fat were also noted.

For the purposes of terminology, the vertebral bodies were defined as the ossification centers. The disk included the end-plate

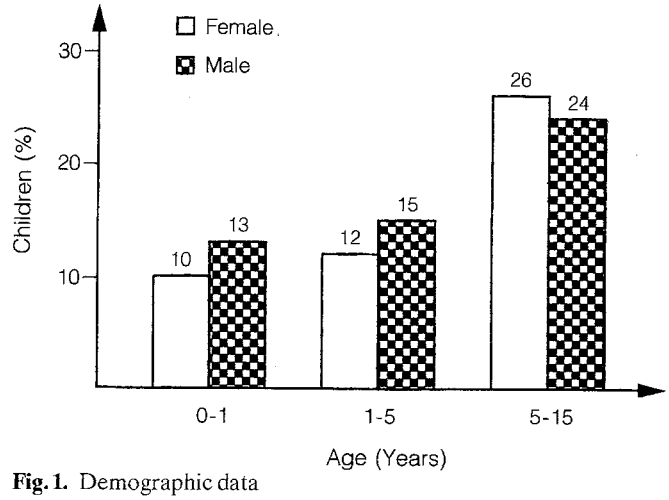

Fig. 1. Demographic data

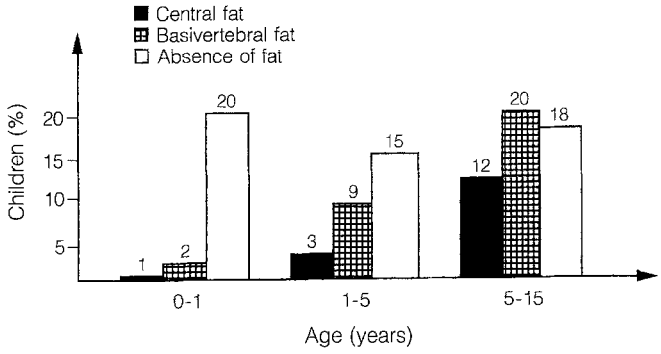

Fig. 2. Age-related fatty marrow distribution patterns

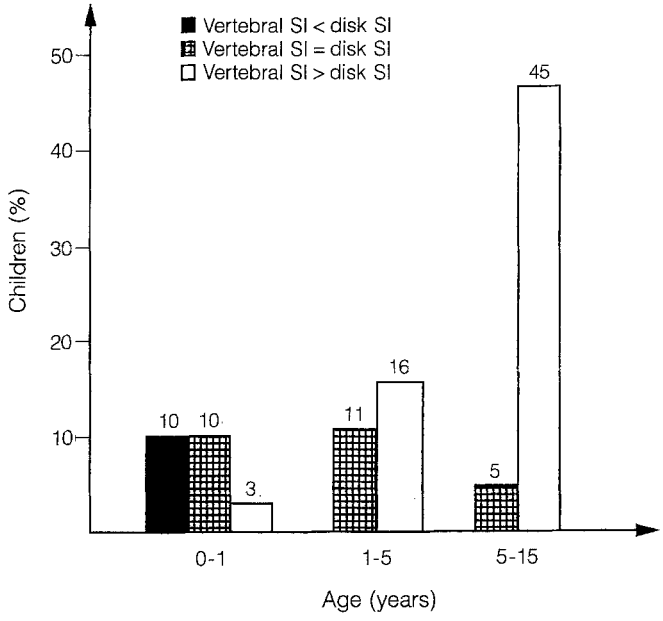

Fig. 3. Age-related changes in vertebral signal intensity (SI) relative to disk SI

hyaline cartilage and the fibro-cartilage forming the annulus fibrosus and the nucleus pulposus, because the hyaline cartilages at the end-plates are not reliably seen as distinct structures on T1-weighted images. This is due to the decreased hyaline cartilage thickness in children older than 1 year [9] and to the chemical shift artifact produced at the fat/water interface between vertebral marrow and end-plate cartilage and disk on T1-weighted images when the frequency encoding gradient is oriented parallel to the long axis of the spine.

For statistical analysis, children were divided into three age groups (younger than 1 year, 1–5 years, older than 5 years). The frequency of each item for each sex and age group was determined and compared using the chi-squared test with or without Yates' correction. Means are given with the 5% confidence range.

Results

The results are summarized in Figs. 2 and 3. The patterns of bone marrow signal and the frequency of the patterns according to patient age are presented in Fig. 2. Data for each sex are not presented separately since no significant sex difference was found.

Three main patterns of marrow distribution were identified. In pattern 1, vertebral body signal was homogeneous, with absence of focal areas of fat (Fig. 4). In pattern 2, fat is found as a triangular area of high SI in the region of the basivertebral vein (Fig. 5). In pattern 3, fatty marrow is detected as a central bandlike area of high SI within the vertebral body (Fig. 6). Pattern 1 (absence of fat), pattern 2 (basivertebral fat) and pattern 3 (central fat) were found in 53% (±10%), 31% (±9%) and 16% (±7%) of the children respectively. The frequency of pattern 1 showed a very significant monotonic decrease with age ($P < 0.001$): 87% (62–97%) in children younger than 1 year, 55% (±16%) in the 1–5 year age group and 36% (±13%) in children older than 5 years.

Values of vertebral SI relative to disk SI are shown in Fig. 3. Vertebral body SI was higher than SI of the adjacent disk in the majority of the children (64±9%) (Fig. 7). Vertebral body SI was similar to or lower than adjacent disk SI in 26% (±8%) and 10% (5–18%) respectively (Figs. 8, 9). A very significant difference in the age distribution was demonstrated ($P < 0.001$), i.e. in older children vertebral SI was higher than disk SI very significantly more frequently. In children younger than 1 year, SI of the corporeal ossification center was similar to or lower than that of adjacent cartilage and disks in 87% (62–97% of cases. In children older than 1 year, vertebral SI was never lower than disk SI. Between the ages of 1 and 5 years, vertebral SI was higher than disk SI in 59% (±18%) of cases. In children older than 5 years, vertebral SI was higher than disk SI in 90% (88–97%) of cases.

Discussion

Knowledge of the normal changes in MRI appearance of vertebral red and yellow marrow with age is essential for the recognition of abnormal conversion and reconversion patterns as well as for identifying infiltration of marrow by tumor and other pathologic processes [2, 3, 10]. Since fat exhibits shorter T1 relaxation times than water, T1-weighted SE images can serve as a guide to marrow distribution. With use of T1-weighted SE images we identified some major bone marrow patterns for the lumbar spine in children.

The general frequency distribution of the patterns as a function of age is consistent with the known progressive conversion of bone marrow as described histologically by Dunnill et al. [11]. In their study of the L2 vertebral body marrow in 94 cadaver specimens, red marrow as a percentage of vertebral body volume declined by nearly half (from 60% to 30%) between the first and eighth decades. Fatty marrow more than doubled during this period from 20% to 50%. Our study shows that fatty conversion is a combination of uniform diffuse replacement and focal replacement. Two major focal replacement patterns were identified, consisting of a basivertebral pattern and a central bandlike pattern.

As expected, these patterns were more frequent in older children (older than 5 years). The basivertebral triangular pattern has been previously reported by Ricci et al. [6] in children and young adults, but their study included only 10 children. Our study confirms that it is a frequent finding, especially in older children. Interesting-

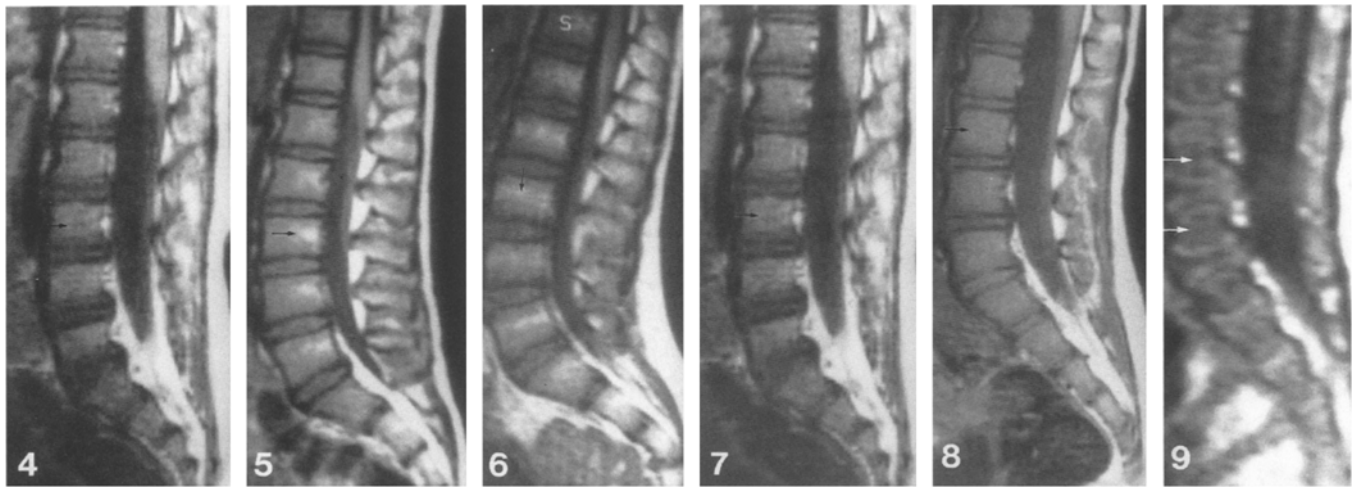

Fig. 4. Pattern 1. Homogeneous hematopoietic marrow *(arrow)* with the absence of a focal area of fatty marrow

Fig. 5. Pattern 2. Basivertebral fatty marrow with a triangular area of high signal intensity adjacent to the site of entry of the basivertebral veins *(arrow)* is commonly seen, particularly in older age groups

Fig. 6. Pattern 3. Central fatty marrow with a central band of high signal intensity *(arrow)* surrounded by a peripheral zone of intermediate signal intensity

Fig. 7. Vertebral bodies are hyperintense *(arrow)* compared with the disk space. This is commonly seen, particularly in older age groups

Fig. 8. Vertebral bodies are isointense *(arrow)* compared with the disk space. This is commonly seen up to the age of 5 years

Fig. 9. Vertebral ossification centers are hypointense *(arrows)* compared with the cartilage and disk space. This is seen only up to the age of 1 year

ly, the bandlike pattern has been previously described as a normal engraftment pattern after bone marrow transplant [12]. It is thus not specific to bone marrow transplantation.

Since degenerative disk diseases are rare in children, assessment of vertebral marrow SI relative to disk SI appears to be practical and useful in the visual interpretation of spinal marrow. Furthermore, since the majority of spinal MRI studies are performed with a surface coil in children, disks are also internal standards which avoid the difficulty of comparing the SI of different structures due to SI drop-off with varying distance from the coil (i. e. subcutaneous fat, paravertebral muscles).

Vertebral SI was higher than disk SI in the majority of the children. In children older than 1 year, vertebral body SI was never lower than disk SI. This finding is in good agreement with the MRI evolution of the infant spinal column as reported by Sze et al. [9], and is related to the prominence of the end-plate hyaline cartilage in infants. Such a pattern in children older than 1 year is therefore suggestive of marrow disorder (either reconversion phenomena or infiltration of the marrow by abnormal cells) and should be investigated. In children older than 5 years, vertebral SI was higher than disk in 90 % of cases. Therefore in this latter age group, demonstration of vertebral marrow SI similar to disk SI should also suggest bone marrow abnormality.

It is noteworthy that in our study the relative SI values of vertebral body and disk were reversed by the age of 5 years in the majority of the children. Sze et al. [6] reported that this occurred at an age of 7 months; however, their study included only children younger than 2 years. Therefore our study suggests that there is a larger range of conversion rates between individuals.

It is essential to underline that the findings of our study are not applicable to gradient echo T1-weighted sequences, since trabecular bone and hematopoietic iron are responsible for a susceptibility effect which leads to the vertebral body exhibiting a lower SI than on the SE sequence [13]. This effect on gradient echoimaging is caused by the lack of rephasing of local magnetic field inhomogeneities by a 180° pulse and as a result the residual transverse magnetization from each pulse is rotated around leading to a steady-state accumulation and a T2* contribution [13].

In conclusion, we have identified some major distinctive patterns of age-related marrow conversion. Knowledge of these patterns (i.e. vertebral to disk SI ratio) should serve as a practical aid to the interpretation of MRI examinations of the lumbar spine in children.

Acknowledgements. The authors express their appreciation to Valérie Chardin for her help in preparing this manuscript.

References

1. Vogler JB, Murphy WA (1988) Bone marrow imaging. Radiology 168: 679–693
2. Moore SG, Sebag GH (1990) Primary disorders of bone marrow. In: Cohen MD, Edwards MK (eds) Magnetic resonance imaging of children. Becker, Philadelphia, pp 765–824
3. Kricun ME (1985) Red-yellow marrow conversion: its effects on the location of some solitary bone lesions. Skeletal Radiol 14: 10–19
4. Ho PSP, Yu S, Lowell AS, Wagner M, Ho KC, Haughton UM (1988) Progressive and regressive changes in the nucleus pulposus. I. The neonate. Radiology 169: 87–91
5. Yu S, Haughton UM, Ho PSP, Sether LA, Wagner M, Ito KC (1988) Progressive and regressive changes in the nucleus pulposus. II. The adult. Radiology 169: 93–97

6. Ricci C, Cova M, Kang YS et al. (1990) Normal age-related patterns of cellular and fatty bone marrow distribution in the axial skeleton: MR imaging study. Radiology 177: 83–88
7. Dooms GC, Fisher MR, Hricak H, Richardson M, Crooks LE, Genant HK (1985) Bone marrow imaging: magnetic resonance studies related to age and sex. Radiology 155: 429–432
8. Hajek PC, Baker LL, Goobar JE et al. (1987) Focal fat deposition in axial bone marrow: MR characteristics. Radiology 162: 245–249
9. Sze G, Baierl P, Bravo S (1991) Evolution of the infant spinal column: evaluation with MR imaging. Radiology 181: 819–827
10. Weinreb JC (1990) MR imaging of bone marrow: a map could help. Radiology 177: 23–24
11. Dunnill MS, Anderson JA, Withehead R (1967) Quantitative histological studies on age changes in bone. J Pathol Bacteriol 94: 10–19
12. Stevens SK, Moore SG, Amylon MD (1990) Repopulation of marrow after transplantation: MR imaging with pathologic correlation. Radiology 175: 213–218
13. Sebag GH, Moore SG (1990) Effect of trabecular bone on the appearance of marrow on gradient-echo imaging of the appendicular skeleton. Radiology 174: 855–859

Announcements

Erasmus Course on Magnetic Resonance Imaging 1993–1994. Commission of the European Communities' ERASMUS Programme: ICP-93-B-1071/12

Participating universities: Katholieke Universiteit Leuven, Københavns Universitet, Rheinisch-Westfälische Technische Hochschule Aachen, Rijksuniversiteit Leiden. Universidade de Coimbra. Università degli Studi dell' Aquila. Università degli Studi di Pisa. Universitaire Instelling Antwerpen. Universität Zürich. Université de Nantes. Université de Rennes. Université Libre de Bruxelles. Université Louis Pasteur de Strasbourg, University of Cambridge, Vrije Universiteit Brussel.

Programme

Musculoskeletal MRI at Aachen (D) – January 31–February 4, 1994
Contact: Prof. G. Adam, Klinik für Radiologie, Pauwelsstraße 1, D-52074 Aachen, Germany. Fax: 0241-875-992.

Cardiovascular MRI at Leiden (NL) – March 2–4, 1994
Contact: Prof. de Roos, Radiologie, Academisch Ziekenhuis Leiden, Postbus 9604, NL-2300 RC Leiden, The Netherlands. Fax: + + 31-71 14-258.

Head and Neck MRI at Brussels (B) – March 21–15, 1994
Contact: Prof. M. Lemort, Institut J. Bordet, Unité de Résonance Magnétique, Rue Heger-Bordet 1, B-1000 Brussels, Belgium. Fax: + + 32-2-543-8977.

Nervous System I at Leuven (B) – April 25–29, 1994
Contact: Prof. G. Wilms, UZ-KUL Gasthuisberg, Medische Beeldvroming, Neuroradiologie, Herestraat 49, B-3000 Leuven, Belgium. Fax: + + 32-16-343-780.

Central Nervous System II at Brussels (B) – June 6–10, 1994
Contact: Prof. D. Balériaux, Radiologie, ULB-Hôpital Erasme, Route de Lennik 808, B-1070 Brussels, Belgium. Fax: + + 32-2-555-66-70.

Abdominal MRI at Pisa (I) – September 19–23, 1994
Contact: Prof. C. Bartolozzi, Catedra di Radiologia, Università di Pisa, Italy. Fax: + + 39-50-551-461.

Programme Coordination: Prof. Dr. P. Beeckman, Academisch Ziekenhuis, Vrije Universiteit Brussels, c/o Prof. R. Luypaert, PRIMIS, MR-Centre, Laarbeeklaan 101, B-1090 Brussels, Belgium. Tel.: + + 32-2-477-5332; Fax: + + 32-2-477-5327.

Registration: Contact module address, the number of participants per module is restricted. A charge will be due for course material. *Application requirements:* Radiologists, MDs, and other medical imaging professionals. Participants who do not have advanced knowledge of the basic physics of MRI are suggested to participate in the module on Magnetic Resonance Basics. *Course format:* Formal lectures, reading sessions and self-teaching sessions, *Certificates:* Evaluation and University certificates per completed module; Erasmus certificate for the full course (7 modules within three years). *Language:* English.

Inaugural Meeting of the PanAfrican Pediatric Surgical Association (PAPSA)

This meeting will be held in Nairobi, Kenya, on March 9–11, 1994, with the theme "Pediatric Surgery in Africa" under the auspices of the World Federation of Associations of Pediatric Surgeons. *For further information please contact:* Prof. H. Rode, Department of Pediatric Surgery, Institute of Child Health, Red Cross Children's Hospital, 7700 Rondebosch, Cape Town, Republic of South Africa. Fax: (021) 689-1287.

First Annual Postgraduate Course: Advances in Radiology

This course will be held from March 24–25, 1994, at the Royal Sonesta Hotel, Cambridge, MA, USA. *Fee:* US$ 350.00; *Credits:* 14. *Sponsor:* Boston University School of Medicine. *For further information please contact:* Amy Gallagher, Boston University School of Medicine, Department of Continuing Medical Education, 80 East Concord Street, Boston MA 02118-2394, USA. Phone: (617) 638-4605.

European Society of Pediatric Radiology 31st Meeting

This meeting will be held in Brussels from June 1–3, 1994. A postgraduate course will precede the congress on May 30 and 31, 1994. *For further information please contact:* E. F. Avni, MD, Radiology, Hôpital Erasme, Route de Lennik 8, B-1070 Brussels, Belgium. Fax: + + 32-2-555-4545, *or* Congress Secretariat Hello-Timelec, rue Dautzenberg 36–38, B-1050 Brussels, Belgium. Tel.: + + 32-2-646-90-80; Fax: + + 32-2-646-96-99.