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Age-related distribution of vertebral bone-marrow diffusivity

Jochen Herrmann[a,b,*], Nina Krstin[a,1], Bjoern P. Schoennagel[a,1], Marjike Sornsakrin[c,2], Thorsten Derlin[a,1], Jasmin D. Busch[a,1], Kay Uwe Petersen[d,3], Joachim Graessner[e], Gerhard Adam[a,1], Christian R. Habermann[a,1]

[a] Department of Diagnostic and Interventional Radiology, Martinistraße 52, D-20246 Hamburg, Germany
[b] Department of Pediatric Radiology, Martinistraße 52, D-20246 Hamburg, Germany
[c] Department of Pediatrics, University Medical Center Hamburg-Eppendorf, Martinistraße 52, D-20246 Hamburg, Germany
[d] Department of Psychiatry, University Clinic Tübingen, Calwerstraße 14 Tübingen 72076, Germany
[e] Siemens AG Healthcare, Lindenplatz 2, 20099 Hamburg, Germany

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ABSTRACT

Purpose: To determine age-related diffusivity changes of the lumbar bone marrow by measurement of apparent diffusion coefficient (ADC) values.
Materials and methods: The local ethics committee approved this study and written informed consent was obtained. The study group comprised 88 individuals including 75 healthy volunteers and 13 patients (48 female, 40 male; mean age 36 years, range 0–84 years). The pediatric cases were recruited from patients. Echo-planar diffusion weighted imaging (DWI) was performed with *b*-values of 50, 400 and 800 s/mm^2. ADC-values were calculated and measured in the 1st and 2nd vertebral body of the lumbar spine. Correlation between age and ADC-values was analyzed with Spearman's rho test.
Results: The ADC values of the vertebral bone marrow of the lumbar spine showed a significant negative correlation with age (rho = −0.398, $p = 0.001$). The mean ADC values ($\times 10^{-3}$ mm^2/s) in the age groups 0–29 years (mean age 18.0 years, $n = 42$) and 30–88 years (mean age 51.6 years, $n = 46$) were 0.54 ± 0.07 and 0.47 ± 0.08, respectively ($p < 0.001$, *T*-test). No significant differences were found between children and young adults.
Conclusion: Bone marrow ADC values of the lumbar spine show a linear decrease with growing age and thereby reflect the gradual changes of cell composition occurring during marrow conversion.

1. Introduction

The magnetic resonance imaging (MRI) appearance of the bone marrow changes during the process of aging on the basis of an altering cellular composition [1]. In the axial skeleton, the marrow lacks fat at birth and the proportion of fatty, yellow marrow increases with growing age. Based on standard T1 weighted spin-echo sequences, the distribution and conversion pattern from red to yellow marrow have been well described [2–4].

Diffusion weighted imaging (DWI) has been introduced as an additional MR application to further characterize bone marrow pathology [5]. Diffusivity can be quantified by measurement of apparent diffusion coefficient (ADC) values [6,7]. ADC values are relatively low in the healthy marrow ($0.2–0.5 \times 10^{-3}$ mm^2/s), which is explained by the restricted mobility of lipid-bound water molecules in contrast to non-lipid bound protons [5]. In bone pathology, ADC values in the vertebral column were usually higher ($0.7–1.0 \times 10^{-3}$ mm^2/s in metastatic diseases and malignant fractures; $1.0–2.0 \times 10^{-3}$ mm^2/s in osteoporotic or traumatic fractures) [8].

As a result of the dynamic changes occurring in the bone marrow compartment, normal values adapted for age and anatomic location are necessary to avoid misinterpretation [9]. A number of DWI studies have focused on the impact of marrow conversion on ADC values. Significant age-dependency has been shown in the parietal and occipital bone, the pelvis, and the femoral epiphysis with substantially higher values in the younger age groups [10–12].

* Corresponding author at: Department of Pediatric Radiology, University Medical Center Hamburg-Eppendorf, Martinistrasse 52, 20246 Hamburg, Germany. Tel.: +49 40 741052712; fax: +49 40 741054964.
E-mail addresses: j.herrmann@uke.de (J. Herrmann), ninakrstin@web.de (N. Krstin), b.schoennagel@uke.de (B.P. Schoennagel), m.sornsakrin@uke.de (M. Sornsakrin), t.derlin@uke.de (T. Derlin), jd.busch@uke.de (J.D. Busch), Kay.Petersen@med.uni-tuebingen.de (K.U. Petersen), joachim.graessner@siemens.com (J. Graessner), g.adam@uke.de (G. Adam), c.habermann@uke.de (C.R. Habermann).
[1] Tel.: +49 040 74105 4029; fax: +49 040 74105 3802.
[2] Tel.: +49 040 74105 8037; fax: +49 040 74105 9646.
[3] Tel.: +49 07071 29 82685; fax: +49 07071 29 5384.

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The purpose of this study was to determine age-related diffusivity changes of the lumbar bone marrow by measurement of apparent diffusion coefficient (ADC) values in healthy volunteers.

2. Materials and methods

2.1. Materials

The local ethics committee approved this prospective study and all participants provided written informed consent. The study group comprised 88 individuals including 75 healthy volunteers and 13 patients (48 female, 40 male; mean age 36 years, range 0–84 years). The pediatric cases were recruited from patients. Exclusion criteria were a history of hematological disorders, bone disease, trauma or chemo- and radiotherapy.

2.2. MR imaging protocol

MR imaging was performed in supine position on a 1.5-T imaging system (Magnetom Symphony; Siemens AG Healthcare, Erlangen, Germany) with a 30 mT/m maximum gradient amplitude and a maximum slew rate of 125 T/m/s, running the latest software version available at the time of the study (Syngo MR VA30, Siemens AG Healthcare, Germany). A six-element body coil placed over the abdomen combined with 2 CP-elements of the spine coil was used for signal reception.

For morphologic evaluation transversal slices of the lumbar spine were measured using a T1-weighted in- and opposed-phase spin-echo sequence (TR 160 ms, TE1 = 2.38 ms, TE2 = 4.76 ms) with a slice thickness of 8 mm, an intersection gap of 2 mm and a field of view (FOV) of 350 mm.

For functional evaluation a transverse free-breathing echo-planar DWI sequence was performed. During this period the volunteers were advised to take shallow breaths. The sequence was adapted with adjustment of the following parameters: 20 sections; section thickness 6 mm; intersection gap 1.8 mm; field of view 350 mm; matrix 192; in plane resolution 2.3 × 1.8 mm; bandwidth 1370 Hz per pixel, optimized for minimal echo-spacing; partial Fourier factor 6/8; TR 3000 ms; TE 74 ms; number of signal averages 10. The following three diffusion gradient *b*-values were used: 50, 400 and 800 s/mm^2. The gradients were applied in three orthogonal directions (3-scan-trace) and subsequently averaged to minimize the effects of diffusion anisotropy. A parallel imaging technique (generalized autocalibrating partially parallel acquisition, GRAPPA) with a reduction factor of two was applied. Section coverage was identical to that used with the transverse T1-weighted sequence. Acquisition time was 4 min 39 s.

2.3. Image analysis

Spherical regions of interest (ROI) were measured in the center of the 1st and 2nd lumbar vertebral body. Each ROI included 24 pixel. ROI placement in the vertebral centers was verified on the sagittal T1 image (scout).

For each echo-planar DWI sequence, a pixel-by-pixel ADC map was automatically calculated, with the gray value of the pixel linearly corresponding to the ADC value expressed in square millimeters per second (mm^2/s). The ADC values were calculated by using a least-square solution of the following system of equations: $S(i) = S_0 \times \exp(-b_i \times \mathrm{ADC})$, where $S(i)$ is the signal intensity measured on the *i*th *b* factor and b_i is the corresponding *b* factor image [13]. S_0 is a variable estimating the exact signal intensity for a *b* factor of 0 s/mm^2 [7].

Data were digitally transferred to the analyzing software MRIcro 1.4 (Chris Rorden, University of Nottingham, Great Britain; http://www.sph.sc.edu/comd/rorden), which lists intensity of each pixel of an ADC map in a single ROI output file per subject.

Table 1
Distribution of lumbar bone marrow ADC-values according to age.

Age group (years)	Median age (years)	*n*	ADC value ($\times 10^{-3}$ mm^2/s)
0–19	5.6	14	0.53 ± 0.04
20–29	25	28	0.54 ± 0.08
30–49	40.5	22	0.47 ± 0.07
>50	61.8	24	0.46 ± 0.09

2.4. Statistical analysis

Spearman's rho test was performed to analyze the correlation between ages and ADC values. A one-way analysis of variance (ANOVA) was calculated to compare the ADC values between the four age-related groups (0–19 years, 20–29 years, 30–49 years, >49 years), followed by Scheffé's procedure for multiple comparisons. *T*-test was applied to investigate the association of ADC values between subjects above and below 29 years of age. P value below 0.05 was considered to indicate statistical significance. All statistical analyses were computed with the Statistical Package for the Social Sciences, Version 18.0 (SPSS Inc., Chicago).

3. Results

The conventional MR sequence did not reveal any abnormalities of vertebral bone in any of the volunteers. Image quality was good in all examinations at all different *b*-values. No substantial distortion artifacts were noted.

A significant negative correlation of ADC values in the lumbar bone marrow to age was found (rho = −0.398, $p = 0.001$) (Figs. 1 and 2). ADC value distribution in the four age-related groups is shown in Table 1. There were significant differences of ADC values ($\times 10^{-3}$ mm^2/s) in patients with age 0–29 years and >30 years (0.54 ± 0.07 and 0.47 ± 0.08; $p < 0.001$). No significant differences regarding ADC values were found between children and young adults (age groups 0–19 years and 20–29 years).

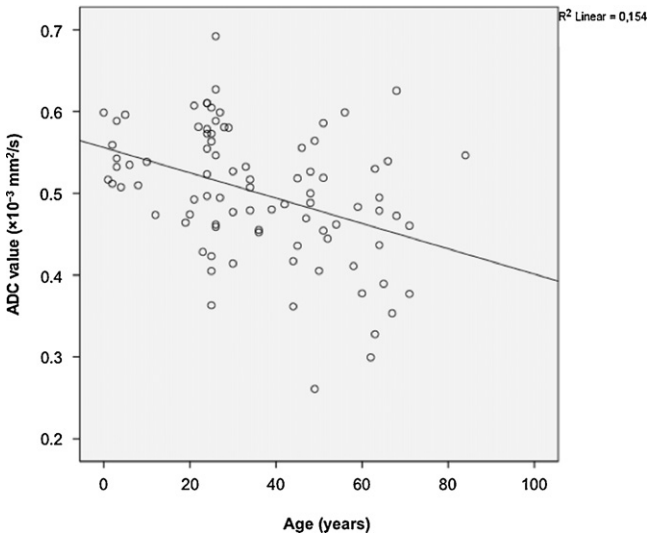

Fig. 1. Scatter diagram displaying the distribution of lumbar bone marrow ADC-values over age.