Compressed sensing acceleration of bone imaging using a 0.3 T open compact MRI for skeletal age assessment

Yasuhiko Terada[1], Daiki Tamada[1], Tomomi Uchiumi[1], Keiichiro Ishi[1], Katsumi Kose[1], Taiki Nozaki[2], Yasuhito Kaneko[2], and Hiroshi Yoshioka[2]

[1]Institute of Applied Physics, University of Tsukuba, Tsukuba, Ibaraki, Japan, [2]Department of Radiological Sciences, University of California Irvine, Orange, CA, United States

INTRODUCTION

Skeletal age of a child can be evaluated by MR images of bones in the left hand. We have shown that an open compact scanner with a 0.3 T permanent magnet provides a comfortable environment for children and facilitates the MR skeletal examination [1]. However, the hand imaging for young subjects often suffered from motion artifacts. Shortening the scan time provides an effective solution to suppress motion as well as a more comfortable and efficient examination. Half Fourier acquisition is a simple way to reduce the scan time, but it requires overscan data to compensate unwanted phase shifts, and indeed the scan time cannot be shorter than 65 % for the scanner that we used. In contrast, compressed sensing (CS) is a promising technique. However, an image is not highly compressive when the signal-to-noise ratio (SNR) is low, and the CS application to bone imaging using a low-field MRI remains a challenge. Here we explore the possibility of CS-based acceleration of bone imaging with the 0.3T open compact pediatric hand scanner. We further show the validity of CS-based skeletal examination.

MATERIALS AND METHODS

A total of 78 healthy children aged from 3.4 to 15.6 (mean 9.5, 53 boys and 25 girls), were recruited from the local community. Written informed consent was obtained from both the child and one of the parents. All MRI measurements were performed under the approval of the ethical committee of our institute. The MRI system consisted of a C-shaped Nd-Fe-B permanent magnet (field strength = 0.3 T, gap width = 12 cm, size = $57 \times 40 \times 41$ cm^3, weight = 450 kg, and homogeneity = 16 ppm over $16 \times 12 \times 5$ cm^3 diameter ellipsoidal volume). A 3D coherent gradient-echo sequence (dwell time = 10 μs; TR/TE = 40/11 ms; FA = 60°; matrix size = $1024 \times 128 \times 32$; FOV = $40 \times 10 \times 5$ cm^3, total acquisition time = 2 min 44 s for full sampling (FS)) was used twice for each subject to image the distal and proximal parts separately. For CS imaging, a random undersampling pattern with variable density (reduction factor = 2) was used for each distal and proximal imaging. The k-space data was acquired using a Cartesian trajectory and undersampled in the phase-encoded direction. The undersampled image was then reconstructed by solving the following optimization problem using the fast composite splitting algorithm [2], $x = \arg \min [\|Fx\text{-}b\|^2/2 + \alpha\|x\|_{TV} + \beta\|\Phi x\|_1]$, where x is an MR image, α and β are constant parameters, b is the undersampled k-space data, F is a partial Fourier transformation, and Φ is a wavelet transform.

Skeletal age was rated independently by two raters (a radiologist A and an orthopedic surgeon B) who were blinded to the children's age, according to the Tanner–Whitehouse Japan RUS system (RUS stands for radius, ulna and the 11 short bones in rays 1, 3 and 5) (Assessment of skeletal age for Japanese children, Medical View, Tokyo, Japan). The rater A rated twice (A1 and A2) to investigate the interrater reproducibility. The values of Cohen's weighted κ [3] were calculated to evaluate agreement of rating for each bone.

RESULTS AND DISCUSSION

Figure 1 shows simulation results for CS reconstruction. The MR image reconstructed from the undersampled data with zero-filling (ZF) (Fig. 1(b)) exhibited aliasing and blurring artifacts. In contrast, the artifacts were removed in the MR image reconstructed from the same data with CS (Fig. 1(c)). Moreover, several bones (circled in yellow), which were not clear in the ZF image, were clearly visible in the CS image. In most cases of the volunteer study, the image quality of CS was compatible with that of FS (Fig. 2). The skeletal age rated from the CS images highly correlated with chronological age (Fig. 3). The interrater and intrarater reproducibilities were high for CS-based rating (Peason's R = 0.962 for A1 and A2, 0.875 for A1 and B, and 0.876 for A2 and B). Figures 4 and 5 show comparisons between FS- and CS-based ratings. The correlation in skeletal age rated from FS and CS images were high (R = 0.945 for A1, 0.855 for B, and 0.946 for A2) (Fig. 4). The weighted κ values were over 0.8 for most bones (Fig. 5). The averaged differences in skeletal age derived from FS- and CS-ratings were almost zero (CS(A1)-FS(A) = -0.21±0.28 years, CS(A2)-FS(A) = -0.07±0.27, and CS(B)-FS(B) = 0.08±0.37). There results reveal the substantial agreement between FS- and CS-based ratings. Fifteen and ten cases were excluded from rating for FS and CS, respectively. The number of cases exhibiting motion artifact was smaller for CS than that for FS (Fig. 6), indicating the suppression of motion in the CS images. Meanwhile, the number of cases exhibiting the low-SNR images was larger for CS, mainly because of the decreased scan time. The improvement in the sensitivity of the RF probe may be required for the more reliable examination.

CONCULSION: Here we investigated and demonstrated the validity of the skeletal age examination using the low-field MRI with CS.

REFERENCES: [1] Y. Terada et al., Skeletal Age Assessment in Children Using an Open compact MRI system, Magn. Reson. Med. 69 (2013) 1697. [2] J. Huang et al., Efficient MR image reconstruction for compressed MR imaging, Medical Image Analysis, 15 (2011) 670. [3] H. L. Kundel et al., Measurement of observer agreement, Radiology **228**, 303 (2003).
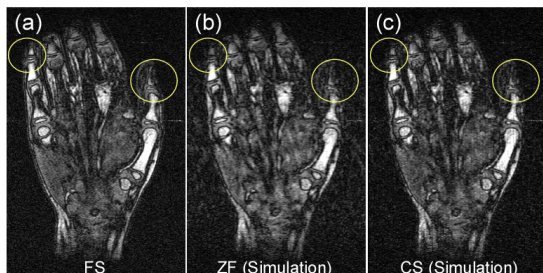
Fig. 1 Simulation results. The images were reconstructed from (a) fully sampled data, and undersampled data with (b) zero-filling and (c) compressed sensing (boy, 8.1 years). The images were trimmed (Image size = 15 cm × 10 cm).
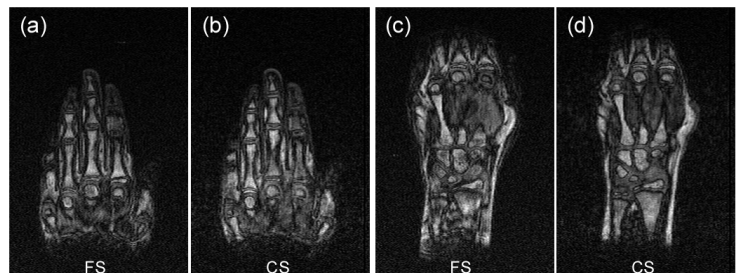

Fig. 2 Examples of MR images acquired with full sampling (FS) ((a) and (c)) and compressed sensing (CS) ((b) and (d)) (girl, 7.5 years). The images were trimmed (Image size = 15 cm × 10 cm).
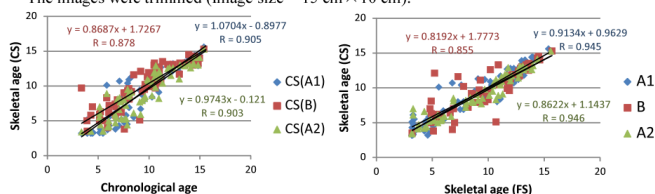

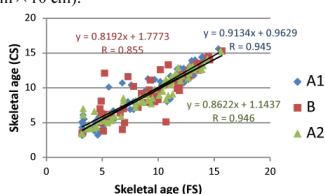Fig. 3 Skeletal age rated from CS images vs. chronological age.

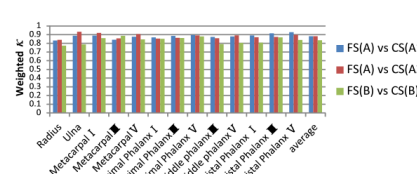Fig. 4 Comparison of skeletal ages rated from CS and FS images.

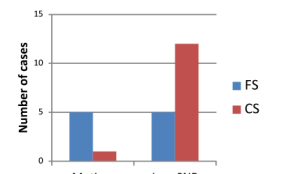Fig. 5 Agreement of rating for each bone between FS- and CS-based ratings.

Fig. 6 Number of cases exhibiting motion artifact and low SNR.