Measurements of child's skeletal age using a 0.3 T open compact MRI system

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INTRODUCTION

Skeletal age, which is a standard measure of child's growth status, is often determined by standard radiographs of left hand. However, the use and possible abuse of radiation exposure is restricted by The International Atomic Energy Agency [1], and an alternative method for the skeletal age assessment is eagerly desired. MRI is non-invasive and a good candidate, though few studies using MRI have been reported. Moreover, 3D imaging capability of MRI would give new maturity indicators (bone volumes and shapes, etc.) that cannot be evaluated by standard radiographs. Here we optimize an open compact MRI system for child's hand imaging and growth assessment. Furthermore we show that the bone volume strongly correlates with skeletal age and is a good maturity indicator.

MATERIALS AND METHODS

Subjects were 93 Japanese healthy children volunteers (age range = 4.1-15.9 years; mean = 9.7 years; 50 boys and 43 girls) recruited from the local community. Their written informed consents were obtained both by themselves and by one of their parents. All of the MRI measurements were performed under the approval of the ethical committee of the Graduate School of Pure and Applied Science, University of Tsukuba.

We used a compact MRI with a permanent magnet (field strength = 0.3 T; gap = 142 mm; homogeneity = 50 ppm over the $22 \times 22 \times 8$ cm^3 diameter ellipsoidal volume; weight = 700 kg), that was originally developed for whole-hand examination for the diagnosis of rheumatoid arthritis [2]. The RF coil was a 16-turn solenoid newly developed for child's hand imaging. It was made by winding a Cu foil (0.1 mm thick) around an oval acrylic pipe (aperture = 10×5 cm^2; length = 22 cm; thickness = 4 mm) and divided in quarters with three capacitors (100 pF) to reduce the stray capacitance between the hand and the coil. The RF coil was shielded by a rectangular RF probe box made of 0.3-mm-thick brass plates and by a 5-mm-thick aluminum ground plate (Fig. 1(a)). To minimize voluntary motion, each subject sat down in a wooden chair with his/her hand loosely fixed onto a FRP plate using a flexible cloth belt and looked at a TV screen (Fig. 1(b)). A 3D coherent gradient-echo sequence was optimized to resolve each bone (dwell time = 20 μs; TR/TE = 40/11 ms; FA = 60°; matrix size = $512 \times 128 \times 32$; FOV = $200 \times 100 \times 50$ mm^3; total acquisition time = 2 min 44 s). The data sets were zero-filled in the phase-encoding direction to equalize voxel sizes in the coronal direction. Each of carpal bone volumes was semi-automatically segmented from the MR images using ITK-SNAP [3] based on the level-set segmentation algorithm. Skeletal age was rated by a reader who were blinded to the chronological age, according to the TW-Japan RUS system (RUS stands for radius, ulna and the 11 short bones in rays 1, 3 and 5) [4]. For segmentation and rating, thirteen cases were excluded because of severe motion artifact or disappearance of the distal phalangeal joint.

RESULTS

Figure 1(c) shows MR images of left hand of a volunteer. The signal-to-ratio was sufficiently high to resolve each bone, and the bone volume was well segmented (Fig. 1(d)). The segmented volume for carpal bones correlated with chronological age (Pearson's correlation coefficient r = 0.874 for boys and 0.852 for girls) (Fig. 1(e)). The bone volume correlated more strongly with skeletal age (r = 0.904 for boys and 0.917 for girls) (Fig. 1(f)).

DISCUSSION

Despite the limited measurement time to avoid unfavorable motion, each bone was well resolved in the MRI images, and fine segmentation of bone volumes could be achieved. The segmented volume of carpal bones had a high correlation with skeletal age. This reveals that the bone volume is a good indicator of child's maturity. Two cases (boys aged 13.9 and 15.1) significantly deviated from the linear correlation curves, possibly because of the large volume of hand itself. The higher correlation may be achievable through the correction with the whole hand volume. With a more sophisticated technique such as full automation of segmentation, the MRI system would become a simple but powerful tool for skeletal age assessment.

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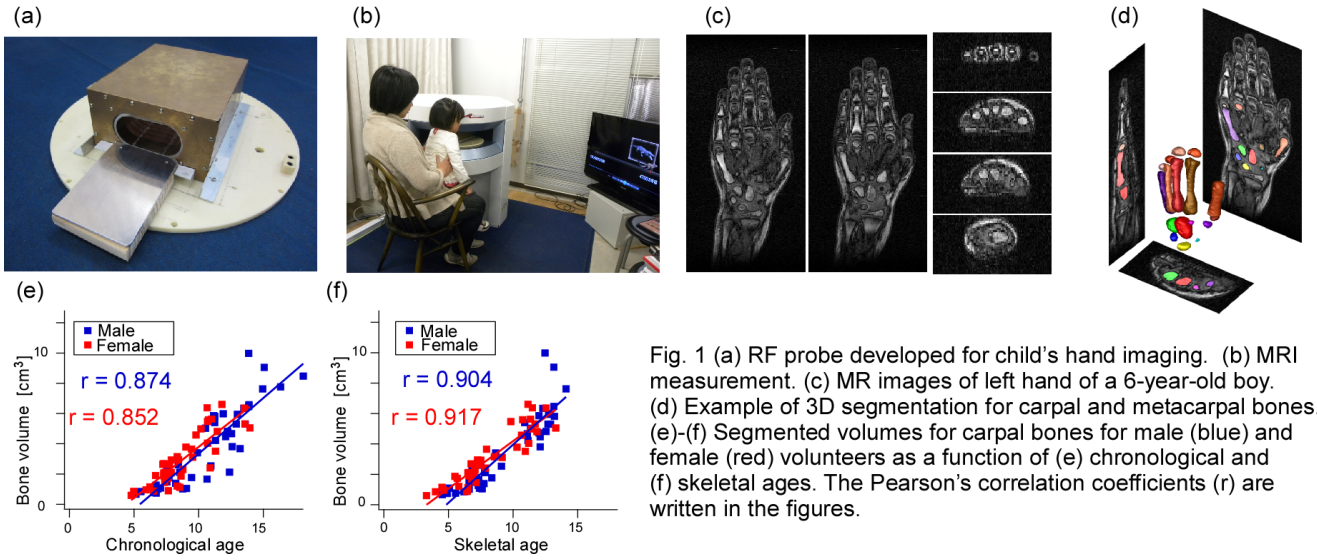

Fig. 1 (a) RF probe developed for child's hand imaging. (b) MRI measurement. (c) MR images of left hand of a 6-year-old boy. (d) Example of 3D segmentation for carpal and metacarpal bones. (e)-(f) Segmented volumes for carpal bones for male (blue) and female (red) volunteers as a function of (e) chronological and (f) skeletal ages. The Pearson's correlation coefficients (r) are written in the figures.