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Applicability of Greulich–Pyle and Tanner–Whitehouse grading methods to MRI when assessing hand bone age in forensic age estimation: A pilot study

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ABSTRACT

Determination of skeletal development is a key pillar in forensic age estimation of living persons. Radiological assessment of hand bone age is widely used until the age of about 17–18 years, applying visual grading techniques to hand radiographs. This study investigated whether Greulich–Pyle (GP) and Tanner–Whitehouse (TW2) grading can be equally used for magnetic resonance imaging (MRI) data, which would offer the huge benefit of avoiding ionizing radiation. In 18 subjects aged between 7 and 17 years a radiograph and an MRI scan of the hand were performed. Epiphyseal ossification of hand bones was rated by two blinded radiologists with both GP and TW2. Correlation between hand MRIs and radiographs was analyzed by linear regression and inter-observer agreement was assessed. Correlation between age estimates from MRI and radiographs was high for both GP ($r^2 = 0.98$) and TW2 ($r^2 = 0.93$). MRI showed a tendency to estimate age slightly lower for 14–18 year-olds, which would be favorable regarding majority age determination in case this result could be reproduced using a currently not existing reference estimation method based on MRI data. Inter-observer agreement was similar for GP in radiographs and MRI, while for TW2, agreement in MRI was lower than in radiographs. In spite of limitations regarding sample size and recruited subjects, our results indicate that the use of GP and TW2 on MRI data offers the possibility of hand bone age estimation without the need for ionizing radiation.

1. Introduction

Magnetic resonance imaging (MRI) has recently seen a tremendous rise in research interest in forensic age estimation of the living [1–4], mainly due to its abandonment of ionizing radiation that is involved in established methods like Greulich–Pyle [5] (GP) and Tanner–Whitehouse [6] (TW2). It promises an unobjectionable, truly non-invasive estimation of unknown chronological age as opposed to the currently established age estimation methods based on X-ray imaging modalities [5,6]. First studies show, that MRI allows to depict with excellent morphological detail the same anatomical structures as investigated using traditional X-ray imaging [7,8]. Additionally, 3D information instead of 2D X-ray projections [1,2] as well as previously unexplored soft tissue contrast becomes available with MRI [3,9]. MRI has also attracted research groups to investigate automatic age estimation techniques [10] due to the promise of improved objectivity in age assessment. Especially methods based on machine learning, where a software aims to derive the age relevant image features from training images with known age automatically in the spirit of BoneXpert [11], have started to appear recently [12,13]. This was enabled by the possibility of collecting a large amount of MRI volunteer data to learn from, which is impossible for X-ray based techniques due to legal

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restrictions. When compared to established X-ray based methods, MRI-based radiological age estimation is currently considered an important research direction. It promises higher accuracy due to improved soft tissue contrast [9,14], wider applicability due to the lack of ionizing radiation [15] and improved objectivity when combined with automatic estimation methods [13].

Age estimation based on radiological data has numerous applications in clinical and forensic medicine. Clinical applications in endocrinology [16] and orthopedic surgery [17,18] involve a clinically indicated X-ray scan to assess biological age, i.e. the developmental stage of an individual. The situation is different in forensic medicine applications, where chronological age of *healthy* subjects, which is prone to biological variation among individuals, has to be estimated [19,20]. Many legal systems disallow the use of ionizing radiation in healthy subjects, with some countries posing exceptions for criminal procedures and asylum seekers. Due to growing migrational challenges caused by economic factors and the consequences of violent conflicts an increasing demand of forensic age estimations in unaccompanied minors can be noticed in many European countries [20]. The latest migrational developments in Europe that started to get extensive media coverage and broad political attention in autumn 2015 are especially showing the large importance of forensic age estimation in the presence of unaccompanied minors without valid identification documents.

Asylum seekers often do not possess valid identification documents, however, an age below 18 years has direct consequences for a person such as the manner of detainment and the rights according to the United Nations Convention on the Rights of the Child. When assessing the age of young, healthy asylum seekers, an ethically correct and fair treatment involves the abandonment of potentially harmful ionizing radiation from X-ray based imaging modalities. Here, MRI has the huge potential to replace the established methods for forensic applications, but also for applications in sports, where healthy participants of unknown or suspected wrong age in junior-level competitions need to be confirmed regarding their claimed age to ensure fairness [15,21,22].

Based on the recommendations of AGFAD, the Study Group on Forensic Age Diagnostics [23], age estimation of children and adolescents consists of a multi-factorial approach, i.e. a combination of a physical examination, the assessment of skeletal age based on an X-ray image of the left hand [24], and a dental examination [25,26] in order to achieve the highest possible accuracy of age estimates. In case skeletal development of the hand is already completed, an additional radiological examination of the clavicle [27] should be performed. For this purpose the replacement of the recommended CT scan [28] with MRI has already been successfully shown [7], and a number of works have recently studied the applicability of existing X-ray/CT-based staging systems for clavicular ossification using MRI as input data [2,29,22]. It is widely agreed that the developmental status of hand and wrist bones are representative for skeletal age until epiphyseal fusion and ossification are completed, which occurs around the age of 17–19 years. This makes hand and wrist age assessment an integral part of multi-factorial age estimation. Besides the development of novel, MRI-specific staging systems, either focusing on the wrist [15] or taking the whole hand into account [3,14], research groups have started to investigate MRI-based age estimation using e.g. the TW2 system in [1], although TW2 was originally developed for X-ray images. Empirical justification of the use of the wide-spread Greulich–Pyle [5] and Tanner–Whitehouse [6] schemes for assessing age from MRI data of the hand is however missing in literature, as well as studies showing correlation between X-ray and MRI ratings on the same subjects.

In this work we study the hypothesis that the assessment of skeletal development and estimation of unknown age can be performed based on hand MRI by using the established reference systems that were developed from X-ray imaging data, similar to other studies involving skeletal development of clavicle and hand from MRI data [2,1,22,29]. This hypothesis is based on the assumption, that MRI and X-ray imaging are capable to depict the same underlying anatomical information on skeletal development. Further, despite depicting it differently, it is assumed that MRI gives at least the same or even better morphological detail to allow an experienced radiologist to mentally generate and interpret growth processes. This ability to evaluate the current state of physical development of input data enables radiologists to compare them to models of normal development as derived from the sole validated reference systems, i.e. those based on X-ray. Therefore, results of a prospective pilot study involving X-ray and MRI scans are presented in this work. This study contributes a comparison of different methods on a data set of 18 subjects regarding the potential of MRI based age estimation to replace examinations that involve acquisition of X-ray images.

2. Material and methods

2.1. Study design

This prospective, cross-sectional study comparing hand X-ray images and MRIs was performed in accordance with the Declaration of Helsinki and was approved by the ethical committee of the Medical University of Graz (ethics proposal: 20-302 ex 08/09). All eligible participants provided written informed consent. Signed statement by their legal guardian was claimed from underage participants. Children and its accompanying parents were recruited at the University Hospital and informed about the study by an investigator. After written informed consent by parent and patient, an appointment for an MRI scan within a few days was made.

2.2. Subjects

In this study, 18 children with ages ranging from 7 to 17 years (4 female, 14 male) were included (mean age 12.6 years, standard deviation 2.9 years). Details about exact chronological age of all 18 subjects are given in Table 1. Recruitment was performed at the Division of General Pediatrics at Medical University of Graz. Participants attended the clinic to determine a possible growth disorder or to perform follow-up examinations during treatment of delayed growth. For this reason, hand radiographs were obtained and the maturity indicators of hand bones were assessed. Only children, who were already planned for a hand radiograph to assess hand bone age because of medical indication, were recruited, such that there was no need for an extra exposure to ionizing radiation. Subjects included in this study fulfilled the following criteria: aged between 7 and 18 years, actually undergoing a hand radiograph because of medical indication, and available written informed consent by parents and patient.

2.3. Radiographic and MR image acquisition

In all cases clinically indicated conventional left hand radiographs were performed at the Division of Pediatric Radiology at Medical University of Graz. Standardized radiographs were taken (Siemens Aristos FX, Siemens AG, Germany) using a tube voltage between 46 and 50 kV and an exposure between 2.5 and 3.2 mAs, depending on the age of subjects.

MRI of the same hand was performed at 1.5 T (Magnetom Symphony, Siemens AG, Germany) at the Division of Pediatric Radiology. A conventional head coil was used for scanning. The left