SKELETAL BONE AGE ASSESSMENT

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1. INTRODUCTION

Bone age assessment is a procedure frequently performed in pediatric radiology. Based on a radiological examination of skeletal development of the left-hand wrist, bone age is assessed and then compared with the chronological age. A discrepancy between these two values indicates abnormalities in skeletal development. The procedure is often used in the management and diagnosis of endocrine disorders and it can also serve as an indication of the therapeutic effect of treatment [1]. Generally, it can indicate whether the growth of a patient is accelerating or decreasing. In many cases the decision whether to treat a patient with growth hormones depends on the outcome of this test.
Another relevant application is in the social field. In fact, a considerable percentage of asylum seekers that come to European countries claim to be a minor to increase their chance to obtain a residence permit. Since these people usually don't have identity papers, determination of the skeletal maturity can help in the determination of the true age of such a person.
This examination is universally used due to its simplicity, minimal radiation exposure, and the availability of multiple ossification centers for evaluation of maturity.
Automatic skeletal age assessment has the potential to reduce the time required to examine the image and to increase the reliability of the analysis.

2. CLINICAL METHODS

The main clinical methods for skeletal bone age evaluation are the Greulich and Pyle (GP) method [2] and the Tanner e Whitehouse (TW2) method [3].
There are several differences between the two methods. The G&P method is most widely used in the Netherlands. This is mainly because the G&P method is faster and easier to use than the TW2 method. However, research has shown that the two methods produce different values for skeletal age and that these differences are significant in clinical practice. According to Bull [4] the TW2 method is the more reproducible of the two, and also potentially more accurate. Although he states that it has never actually been shown to be more accurate.
Both methods rely on radiographs taken from the left hand. Before we start a detailed examination of the two methods it is vital to know a little about the anatomy of the hand in order to understand some of the terms used.

2.1 THE GREULICH AND PYLE METHOD

In 1929 preliminary studies were started at the Western Reserve University School of Medicine in Ohio. These studies were the base for a long-term investigation of human growth and development. A large number of children of different ages were enrolled in the study. These children had radiographs taken of their left shoulder, elbow, hand, hip and knee. In the first postnatal year an examination was conducted every three months, from twelve months to five years they were examined each 6 months and annually thereafter. In total the study ran from 1931 until 1942.
In 1937 an atlas, "Atlas of Skeletal Maturation of the Hand", was published by Todd [11]. This atlas was based on a part of the data collected in the such study. Greulich an Pyle based their atlas partly on the atlas by Todd. Since their atlas was first published in 1950 they were able to use all the radiographs obtained in the original study. In total they had at their disposal from two to twenty-one hand radiographs made at successive examinations of each of 1000 children.
In their method for each of these bones an elaborate description of its developmental stages is included. The descriptions are more a general guideline to the development of each bone in the hand than an instruction on how to ratea bone.
Most institutions use a more rapid modified version of the original, which is also potentially less accurate. That version is described below. In order to determine the skeletal age using the modified Greulich and Pyle method one uses the atlas that they have developed. The sex of the patient is one of the most important pieces of information, because females develop quicker than males. The atlas is divided into two parts, one for the male patients and one for the female patients. Each part contains standard radiographic images of the left hand of children ordered by chronological age.
The first step in an analysis is to compare the given radiograph with the image in the atlas that corresponds closest with the chronological age of the patient. Next one should compare it with adjacent images representing both younger and older children. When comparing the radiograph against an image in the atlas there are certain features a physician should use as maturity indicators.

These features vary with the age of the child. In younger children the presence or absence of certain carpal or epiphyseal ossification centers are often pointers for the physician about the skeletal age of a child. In older children the shape of the epiphyses and the amount of fusion with the metaphysis is a good indicator of skeletal age.
Once the atlas image that most resembles the radiograph is found the physician should conduct a more detailed examination of the individual bones and epiphyses. When the physician is sure that the matching radiograph has been found, she can find the skeletal age printed at the top of the page.

2.1 TANNER AND WHITEHOUSE METHOD

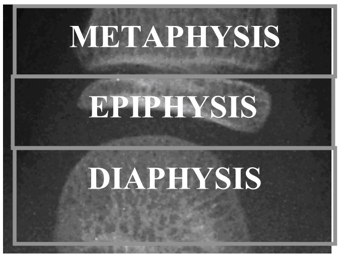
The TW2 method doesn't use a scale based on the age, rather it is based on a set of bone's standard maturity for each age population. In details, in the TW2 method twenty regions of interest (ROIs) located in the main bones are considered for the bone age evaluation . Fig.1 shows some of the bones of interest. Each ROI is divided in three parts: epiphysis, metaphysis and diaphysis expecially in young people, it is possible to identify these different ossification centers in the phalanx proximity (fig.1(b)).
The development of each ROI is divided into discrete stages and each stage is given a letter (A,B,C,D, . . ., I) as is shown in fig.2.
A numerical score is associated with each stage of each bone (Table 1). By adding the scores of all ROIs, an overall maturity score is obtained. This score is correlated with the bone age differently for males and femalesby the function shown in fig. 3. The TW2 method has a modular structure which makes it suitable for automation. For the TW2 method, three score systems have been developed :

- *TW2 20 Bones*: characterized by twenty bones including the bones of the first, third and fifth finger and the carpal bones.
- *RUS:* considers the same bones of the TW2 method except the carpal bones;
- *CARPAL*: considers only the carpal bones.

A number of algorithms for automated skeletal bones age exist in the literature. Most of these algorithms are based on the Epiphises – Metaphises ROI (EMROI) Extraction and leave the Carpal ROI, ulna and radius out of consideration.

(a)

1. **First metacarpal**
2. **Proximal phalanx of the thumb**
3. **Distal phalanx of the thumb**
4. **Third metacarpal**
5. **Proximal phalanx of the third finger**
6. **Middle phalanx of the third finger**
7. **Distal phalanx of the third finger**
8. **Fifth metacarpal**
9. **Proximal phalanx of the fifth finger**
10. **Middle phalanx of the fifth finger**
11. **Distal phalanx of the fifth finger**



(b)

Fig.1 (a) Analyzed ROIs in TW" method, (b) division of a ROI in metaphases, diaphises and epiphises.

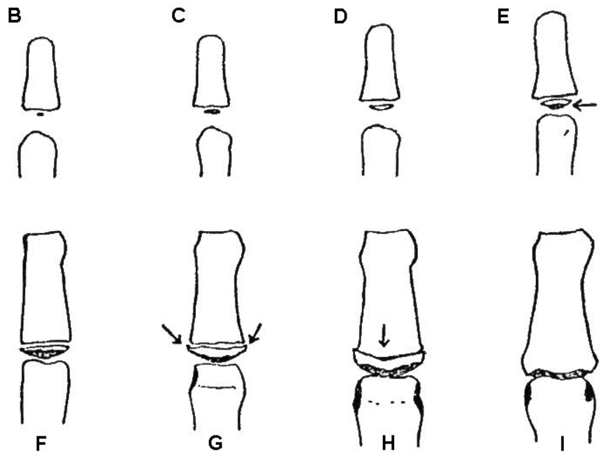


Fig.2 - Discrete stages for a ROI

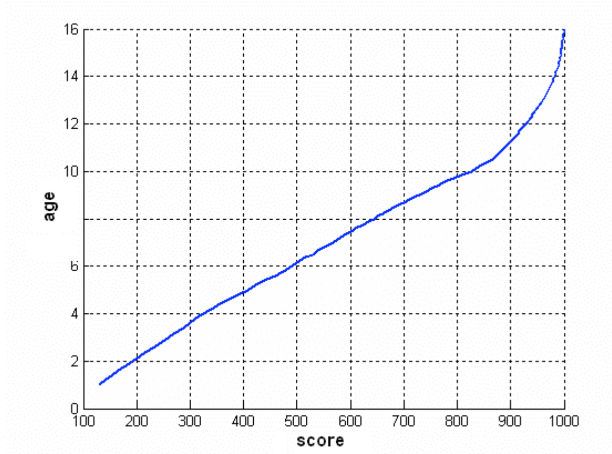


Fig.3 - Correlation between score and skeletal age for male

TABLE I
NUMERICAL SCORE FOR EACH BONE

	Female Stage								Male Stage							
	B	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
TW2 Bones																
Radio	17	19	25	33	54	85	99	106	15	17	21	27	48	77	96	106
Ulna	22	26	30	39	60	73	80	0	22	26	30	39	56	73	84	0
Metac. I	5	6	11	18	24	29	31	33	4	5	11	19	24	28	30	32
Metac. III	3	5	7	11	17	23	24	26	3	4	6	10	16	22	23	25
Metac. V	3	4	7	12	18	22	24	25	3	3	6	12	17	21	23	25
Fal. Prox. I	5	5	8	14	24	29	30	32	4	5	8	15	23	28	30	32
Fal. Prox. III	4	4	7	13	20	24	25	26	3	4	6	13	20	23	24	26
Fal. Prox . V	4	4	7	13	19	23	24	25	3	3	6	13	19	22	23	25
Fal. Media III	4	4	7	13	20	23	24	25	3	4	7	13	19	22	23	25
Fal. Media V	4	5	8	14	20	22	22	23	4	4	8	14	19	21	22	23
Fal. Distale I	5	5	8	15	24	31	32	34	4	4	7	14	23	30	31	33
Fal. Dist. III	3	4	6	10	17	22	23	24	3	4	6	10	16	21	22	24
Fal. Distale V	3	4	7	11	17	21	22	23	3	4	7	11	16	20	21	23
Capitato	53	56	61	67	76	85	113	0	60	62	65	71	79	89	116	0
Uncinato	44	47	53	64	74	85	97	109	42	44	49	59	70	81	92	106
Piramidale	8	12	19	28	36	46	63	0	7	10	17	28	38	45	62	0
Semilunare	10	14	20	27	35	46	60	0	10	13	20	27	36	44	60	0
Scafoide	13	17	23	29	36	44	57	0	14	18	23	30	35	42	58	0
Trapezio	12	14	20	25	32	39	49	59	12	15	21	28	34	39	47	59
Trapezoide	13	16	20	24	31	40	57	0	14	16	20	23	32	39	56	0

3. STATE OF ART FOR AUTOMATIC SKELETAL BONE AGE ASSESSMENT

In all the developed method the algorithms are divided in several step: image preprocessing, background removal, orientation correction, image segmentation and features analysis.
The first semi automated system has been developed by Michael [4] around the 1989. The author claims that the system was able to automatically segment the bones in a hand radiograph but large scale tests were not done. Before segmentation starts the image is first preprocessed. The goal of this preprocessing is to normalize the image gray scale so that the later segmentation step will be more robust. The program first segments the entire hand (bones and flesh) from the background using a thresholding operation. After this a model-based method is used to find the bones in the hand. This method uses knowledge of the relative positions of the bones in the hand with respect to each other and to the contour of the hand. After the approximate position of a bone is found its contour is given by an adaptive contour following algorithm.
A methods for a skeletal bone age analysis have been developed by Pietka et al. in [5]. In this article a PROI is defined as the ROI which contains all the phalanges and epiphyses. To find it a number of steps are needed: First the lower boundary of the PROI is detected by scanning a horizontal line over the hand image to search for the soft tissue between the first index finger and the thumb. The upper boundary is a horizontal line at the tip of the third finger. After this two vertical lines are scanned from the middle of the hand to both the left and the right boundary of the hand. Each of the lines stop on the last pixel belonging to the hand, now the upper, lower, left and right boundary of the PROI have been defined. To segment the bones and epiphyses from the PROI it is first turned into a gradient image using two Sobel kernels. The result is thresholded using an empirically determined value to find the edges of the bones and epiphyses.
The concentration of pixel values at the end of a phalanx is up to 50% higher than in the central part. Once a window has been determined that contains the epiphysis, a horizontal line is scanned over the window. The location of the smallest intersection with the segmented finger is marked as the line that separates the phalanges. In this fashion the borders between the third distal, middle and proximal phalanges are marked. These can now be measured. This method was tested on 50 pediatric hand CR (computed radiography) images and the results were compared to the measurements of an independent radiologist. The mean difference between these two measurements was 0.02mm with a mean standard error of 0.08mm.
Manos [7] developed a segmentation method for the wrist using region growing and merging. The technique that is used is basically a bottom up approach.
In [8] and [9] an approach to find the EMROI of the phalanges using Active Shape Models [10] is proposed. Another interesting approach has been proposed by [11]. The authors describe a system which implements the TW2 method using a neural network architecture. Each bone complex is localized on the image, and preprocessed using either a Gabor transform or a multi-scale Difference of Gaussian filtering.

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