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Review Article

A Bone Age Assessment – A Critical Review

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ABSTRACT

Radiography of the hand & wrist is the commonest modality used to calculate bone age. Automated methods for evaluation of hand and wrist radiographs are also being developed which reduce inter rater variability compared to manual methods. Non radiation based techniques of visualizing hand & wrist bones such as ultrasonography for bone age calculation have been theorized but are not as accurate as radiographic methods. MRI based methods are being developed but require more research. Dental age is an alternate form of bone age determination, which also gives an estimate of skeletal maturity. The accurate age assessment is required for applying correct treatment modality in pediatric patient as well as for forensic purpose. The hand wrist radiograph is considered to be the most standardized method of skeletal assessment. In the present review we will discuss about the various methods of hand wrist skeletal maturity assessment.

Sources of Data/Study Selection: Recent articles published between years 2004-2016 obtained from online search engines Pubmed and Google Scholar were used in preparation of this review.

Key words: Bone Age Measurement, Diagnostic X-Ray Radiology, Hand wrist radiograph, chronological age, Greulich and Pyle atlas, Clavicle.

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INTRODUCTION

Age assessment of living persons or skeletal remains is a common requirement in forensic practice and bioarchaeology. For living persons, an age assessment may be performed under a number of circumstances such as determining criminal responsibility , seeking asylum ,school attendance ,employment, and marriage, whereas in forensic anthropology and forensic odontology ,age estimation is an important step in the identification of human remains. [1] In bioarchaeology, age estimation is the first step in determining population characteristics, for example specific mortality rates.

Additionally skeletal maturity or bone age (BA) assessment is a routine procedure in all pediatric radiology departments. Pediatricians and endocrinologists recognize that the assessment of BA by means of a hand and wrist radiograph reflects the child's biological age.[2] Bone age is an effective indicator for diagnosing various diseases and determining the timing of treatment. The aim of bone age assessment is to evaluate growth and maturity and to diagnose and manage pediatric disorders. Therefore, the accuracy of bone age assessment is very important.

This is accomplished with a variety of methods, all of them comparing a given radiograph to various standards, averaging or summarizing the maturity of several bones, followed by designation of a BA. In fact, a radiograph of the hand and wrist can at best reflect the maturity of the bones that are depicted on that film, and the recognition of the shapes and changes of configuration of bones [3].

Although these manual bone age assessment methods have been used for a long time, the main problem with these methods is inter- and intra-observer variability. Recently, several computerized systems for bone age assessment have been developed. In this review, we are describing about the progress in assessment methods and clinical applications of bone age.[4]

DIFFERENT BONE AGE ASSEMENT METHODS

1 Bone age assessment by hand visualisation- 1st method which most commonly used , as hand and wrist region is made up of numerous bones[5] , these bones show predicatableand schedulded pattern of appearance , ossification and union from birth to maturity.[3] Hence this region is one of the most suited to study growth. A standard posterior-anterior (PA) view of the hand and wrist is ideal for visualization of features of hand bones.[6]The hand radiographs are quite safe to obtain as the effective[7] dose of radiation received during each exposure is between 0.0001-0.1 mSV[4].This dose is less than 20 minutes of natural background radiation or the amount of radiation received by an individual on a 2 minutes transatlantic flight.[8,9]

2. The Greulich& Pyle (GP) method- Skeletal maturity follows a predictable series of changes. Assessment of skeletal maturity is important in the care of children with certain endocrine disorders[10]. Skeletal maturity can be estimated by comparing the radiographic appearance of the child's hand and wrist bones with the radiographic appearance of a healthy group of children of the same age[11]. Greulich and Pyle's Radiographic Atlas of Skeletal Development of the Hand and Wrist (G&P)[12] is commonly used as a reference standard for bone age-assessment based on the presence, size and shape of bones (or secondary ossification centers) in the left hand and wrist.
G&P is composed of radiographs from an ethnic, economic and geographic subset of children born more than half a century ago.[13]It contains reference images of male and female standards of the left wrist and hand from birth till 18 years for females and 19 years for males. Also, explanation regarding the gradual age related changes observed in the bone structure is provided with each standard image. Bone age is calculated by comparing the left wrist radiographs of the subject with the nearest matching reference radiographs provided in the atlas which are standard for different ages provided in the atlas.This method is simpler and faster than other radiograph based methods.

3. Tanner Whitehouse method (TW2)methods- The Tanner &Whitehouse (TW) method in contrast is not based on the age ,rather there are actually three different TW2 methods: the radius-ulna-short bones (RUS) method for evaluating the 13 long or short bones (i.e., the radius, ulna and short bones of the first, third and fifth fingers), the carpal method for evaluating the 7 carpals and the 20-bones method for evaluating the 13 long or short bones and 7 carpals.[15] For the purposes of this review, here we are using the level of maturity for 20 selected regions of interest (ROI) in specific bones of the wrist and hand in each age population.[12] The development level of each ROI is categorized into a stage (from stage A to H or I). Afterwards, each stage is replaced by a score, and a total sore is calculated. Finally, the total score is transformed into the bone age. This score is correlated with the bone age separately for males and females. This method is more complex and require more time than other methods.

4. Fels method- This method is based on longitudinal records of 355 boys and 322 girls in the Fels Longitudinal Study between 1932 and 1977 and the sample was from middle-class families in south-central Ohio, USA. Specific maturity indicators for the radius, ulna, carpals, and metacarpals and phalanges of the first, third and fifth arrays were described.16 Grades are assigned to each depending on age and sex.[17] Ratios of linear measurements of the widths of the epiphysis and metaphysis of the long bones are also used and presence (ossification) or absence of the pisiform and adductor sesamoid is noted. Grades and width measurements are entered into a program that calculates SA (skeletal age) and standard error. Contributions of specific indicators in computations are weighted depending on age and sex. The standard error provides an estimate of the error in an assessment; It is a unique feature not available with othermethods. Standard errors increase as skeletal maturity is approached because indicators that are available for assessment and in turn calculation of SA are reduced.

5. The 3 Scoring method- All of the teeth of the lower left jaw except the third molar were rated on an 8-stage scale ranging from A to H according to the system of Demirjian et al. For the dental age(DA) estimation, we used the revised method of Demirjian and Goldstein (subsequently referred to as the Demirjian method) in which the maturity scores for each tooth are summed to obtain an overall maturity score, which is converted into a DA using tables (separate for boys) .
For the method described by Chaillet et al. (subsequently referred to as the Chaillet method), the sum of the specific maturity scores was converted to a DA using the appropriate tables for boys and girls.[1]
For the two Willems methods, the sum of the maturityscoreofeachtoothdirectlyprovidedtheDAinyears.This maturity score was determined either separately for boys and girls (subsequently referred to as the Willems I method) or non-sex-specifically (subsequently referred to as Willems II method).[18] The CA was subtracted from the DA; a positive result indicates an overestimation, and a negative result indicates an underestimationofage.
Therefore, dental maturity is widely used to evaluate growth and development of children, and Demirjian's method is one of the simplest, most practical, and widespread methods of DA estimation[19] .This study confirmed the overestimation of dental age using Demirjian's standards for all age groups in children aged 4–14 years. These standards were not suitable for the studied sample of French children. The Willems I, Willems II, and Chaillet standards were found to be more accurate. For the population studied, if the ancestry and the sex are known, the Chaillet standards were found to be more accurate. [20] If the ancestry is unknown, the more appropriate method is that of Chaillet et al., which considers the worldwide variability in tooth maturation. If

the sex is unknown, the Willems II method is suitable. We suggest that differences in the birth year in the reference and target samples influence the accuracy of the four tested methods.[21]

6. The Kreitner method- In order to assess the degree of apophyseal iliac crest ossification, a modified classification scheme after Kreitner et al. was used. The original four Kreitner stages are commonly applied in medicolegal, anatomical and radiological studies aiming on the investigation of the medial clavicular epiphysis and the anterior iliac crest, respectively. During the twentieth century, the determination of the iliac crest maturation in conventional radiographs to identify the respective stage of the so-called Risser sign has been long established in the field of radiology and clinical orthopaedics[22]. Literature review suggests that the ossification of iliac crest apophysis is not uniform resulting in discrepancies while using this method for bone age calculation. This is why it is not used as a replacement of bone age calculation from hand radiographs. Newer methods are being developed to compute bone age from iliac radiographs but further studies are needed to compare different grading systems.

7. Automatic Skeletal Bone Age Assessment- Inamodernradiologydepartmentitisbecomingincreasingly difficult to maintain a high standard of bone age rating, because the rating is often done by different persons, and there is a tendency that less time is spent on this task As a consequence, bone age rating is associated with a considerable rater variability, the size of which is often unknown.

The pediatrician, who is using the bone age to diagnose the child or to monitor the treatment, is therefore often uncertain about the reliability of the rating.[23] A reliable rating is important as a basis for a more patient specific treatment, and bone age is a fundamental characteristic of the child that influences the best practice in many areas , change the status of bone age assessment by introducing a new, computerized, and 100% automated approach called BoneXpert[24.]BoneXpert makes use of technologies from medical image analysis, statistics, and machine learning, which have not been used previously for this task, but at the same time the method is to a large extent based on the insight into human biology exposed in the classic book in this field Assessment of Skeletal Maturity and Prediction of Adult Height (TW3 Method) which also defines the specific Tanner–Whitehouse (TW) method for bone age rating. The realization of this vision has been remarkably slow[25].
Tanner was among the first to present a computerized system, CASAS ,[12] which was received with some interest in the pediatric endocrinology community . Other systems came along from Hill, Sato , and Pietka, but none of these became common in clinical practice.
A common problem of these systems is their limited ability to reconstruct the bone borders, i.e., to automatically locate anatomically meaningful points at the relevant locations on each bone. As a result, these systems are not fully automated; they are able to process at most 90% of the cases, so they must be supervised by an expert. In the first versions of CASAS the bone reconstruction was actually done manually by the user, who placed the film under a video camera and adjusted the location of the film and the magnification for each bone to match a template and the interpretation was then done automatically. This was an elegant way to initiate the computerization.
The method, called Bone Xpert, reconstructs, from radiographs of the hand, the borders of 15 bones automatically and then computes "intrinsic" bone ages for each of 13 bones (radius, ulna, and 11 short bones). Finally, it transforms the intrinsic bone ages into Greulich Pyle (GP) or Tanner Whitehouse (TW) bone age. The bone reconstruction method automatically rejects images with abnormal bone morphology or very poor image quality. The architecture of Bone Xpert divides the processing into three layers. Layer A reconstructs the bone borders, layer B computes an intrinsic bone age value for each bone, and layer C transforms the intrinsic bone age values to either TW bone age or Greulich Pyle (GP) bone age using a relativelysimple postprocessing. An overview of the layers and related prior work follows. The Appendix introduces skeletal maturity and the TW and GP rating systems.

8. Ultrasonographic method: There are several reports regarding ultrasonographic evaluation of bone age using an instrument called BonAge® (Sunlight Medical Ltd, Tel Aviv, Israel). This instrument utilizes an armrest between two transducers to support the subject's hand and wrist, and ultrasonic waves pass through the subject's distal radius and ulnar epiphysis.[26]
Afterwards, software is used to calculate the bone age using an algorithm based on measurements of sound velocity and the distance between the two transducers. Both Mentzel et al. and Shimura et al. reported that there were high correlations between the bone age evaluated by BonAge® and the GP or TW2 methods.
In contrast, Khan et al. reported that BonAge® tended to over-read delayed bone age and under-read advanced bone age compared with both the GP and TW3 methods; they concluded that BonAge® should not be considered a valid 26replacement for determining radiographic[27] bone age. Further studies of bone age assessment by ultrasonography are needed in larger populations, different ethnic groups and children with growth disorders. [28]

10. Visualisation by MRI -The use of magnetic resonance imaging (MRI) of the clavicle as a method of forensic bone age determination has, to our knowledge, only been investigated in cadavers by Schmidt et al. In their article the authors conclude that MRI of the clavicle has the potential to become useful in age estimation procedures, but that a specific MRI protocol needs to be developed and that more extensive research is necessary.[29] We prospectively investigated whether high resolution 3T MR imaging of the clavicle could become a new imaging method in forensic bone age determination and compared it with conventional radiography.

CONCLUSION

The correct estimation of developmental age is required by pediatric endocrinologist and pediatric orthopaedic surgeon for choosing the effective treatment procedure in a child patient. Moreover, the accurate age assessment has its importance in forensics also. Therefore various bone age assessment methods especially the hand –wrist radiography is a boon for medical science. Various methods of hand –wrist assessment has been devised, the latest being the automated systems. From the above review we can conclude, that no method of hand wrist radiography is flawless and lot of research is required in this direction to obtain a desired hand wrist radiographic technique for skeletal age assessment.

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