Bone age for chronological age determination. Recommendation from the ESPR musculoskeletal task force group.

Introduction

In some situations, there is a need to verify or determine a person's chronological age. It might be unknown or intentionally falsified e.g. in legal cases regarding child labour, sexual assault, prostitution, and sometimes for elite athletes.

However, most commonly, age determination is needed for young asylum seekers. Every year, young unaccompanied asylum seekers arrive in European countries, many without knowing how old they are or unable to provide formal documentation of their age.

To ensure that children receive their rights and that adults are not treated as children, it is necessary to assign a chronological age to these individuals. Evaluation of skeletal maturation of the hand development has been used for age assessment of asylum seekers in many countries. The method has been criticized for its lack of precision.

«The Radiographic Atlas of Skeletal Development of the Hand and Wrist» by Greulich and Pyle (The GP atlas) is the most widely used atlas when age estimation is based on radiography of the hand. The GP atlas was published in 1950 and was originally developed to assess the skeletal development of an individual with *known chronological age* to confirm normal skeletal development, to assess growth and growth potential and to estimate final height but not to assess chronological age (Ref 1). Normal skeletal development is defined as a skeletal age within two standard deviations from the reference development stage for a given chronological age. This normal reference graph cannot automatically be reversed to find the reference interval for chronological age based on a given bone age.

Probability of age distribution from a given bone age

Reference–interval for chronological age

Several factors influence the skeletal maturation in a growing individual, of which normal biological variation is overall the largest factor. Other factors that may influence skeletal maturation, and cause additional variation in skeletal maturation between individuals of the same age, are medical conditions, medication, nutrition and ethnicity (Ref 2).

The question in chronological age determination is whether it is possible to construct the probable chronological age or age reference-interval for an individual based on his or her bone age as assessed by the Greulich and Pyle atlas.

In 2016, the Norwegian Institute of Public Health was assigned national professional responsibility to evaluate current methods, in a bid to improve chronological age estimation when unknown, and potentially develop a tool for chronological age estimation based on hand and dental radiographs. The Department of Forensic Sciences, in cooperation with the Knowledge Centre for the Health Services decided to conduct a systematic search of the scientific evidence for such medical age estimation methods. The search found 658 potentially relevant publications for age estimation using radiographs of the hand. Two researchers independently considered the full text of these studies and included 17 studies with results presenting age estimation based on the Greulich & Pyle atlas (Ref 3).They found that the majority of studies addressing the correlation between chronological age and bone age assessed from radiographs of the wrist, present results as the average difference between chronological

age and GP skeletal age within age groups. Four studies presented results as average chronological age within maturation stages from the Greulich and Pyle atlas. Three of these studies were influenced by the age composition of the included study population, which is a bias termed "age mimicry". This means that the average age observed in each developmental stage is affected by the included age range and number of participants in each age-group.

Only one study, by Chamoitre et al, presenting average chronological age for each G&P maturation stage, had a large study population with a relatively even distribution between age groups (Ref 4). Their results are based on data from 2614 individuals from France, with a mixed ethnic background and a robust study design avoiding misleading results from age-mimicry. The key points of Chamoitre's paper were:

-The GP atlas is still accurate at the present time.
-There is a high correlation between bone age and chronological age.
-Individual variability must be known when GP is used in forensic cases.
-Prediction intervals (95%) are large; around 4 years and up to 6 years after 10 year of age.

To test the reproducibility of this paper the Norwegian Institute of Public Health collected raw-data from numerous publications on the correlation between chronological age and bone age and included more than 14000 individuals in their analyses. They found that Chamoitre's results were reproducible and representable (Ref 3).

This means that the chronological reference interval for each bone age is at least four years and up to six years. If we take the additional effect on skeletal maturation from potential medical conditions, nutrition, medication and ethnical variation into consideration, the interval may even be wider.

Bone age in the assessment of whether a person is over or under 18 years of age

Professor of Medical Statistics Tim Cole has also investigated how informative bone age is for judging whether an individual is under 18: "It turns out that the amount of information it contains depends on the age claimed by the individual (as opposed to their simply being under 18). In some circumstances bone age is informative but usually it is not. The issue here is the size of the standard deviation (SD) of the difference between bone age and chronological age, which is 15 months or more. So the confidence interval around the chronological age estimated from bone age is ±30 months (i.e. ±2 SDs), a range of 5 years. This lack of precision impacts on the value of bone age as evidence, and renders it uninformative except in extreme cases" (Ref 5).

This reflects another problem with probability of age distribution. The reference age interval from a given skeletal maturation depends on a pre-defined possible upper age of the investigated individual or the population it is used on. The upper age chosen is crucial for the calculated age prediction intervals and the percentage under a certain age or for the likelihood of a person being under or over 18 years. This applies particularly to the uppermost maturation stages, since hand development has an end stage that lasts for the rest of the individual's life. This means that the statistical relevance of any method only applies if all the individuals actually have chronological age below the chosen upper limit, which is a paradox since the chronological age is what we seek to find.

Conclusion
1. There is a clear correlation between chronological age and skeletal maturation.
2. The Greulich and Pyle atlas is still valid, however most relevant data cover populations from a relatively limited geographic area.

3. All studies show that the exact chronological age cannot be determined based on a person's bone age. It is impossible to determine whether a person is over or under 18 years based on bone age of the hand/wrist.
4. It is not possible to overcome the biological variation, hence the 95% prediction interval for chronological age is wide for each bone age developmental stage. The study with the most robust design (Chaumoitre 2017) shows that the prediction interval is a minimum 4-6 years.
5. There is no/sparse literature on the additional effect of malnutrition/stress/ health related issues that can increase the chronological age reference-interval calculated from bone age.
6. Using correct mathematical models, it may be possible to calculate statistical *probabilities* for a chronological age range for each skeletal maturation stage on a group basis, assuming that the data on which such a model is based is representative of all ethnicities and takes influences of nutrition and medical conditions for skeletal variation into account, which to date is not feasible. Furthermore, since there is no end-point of chronological age after full skeletal maturation, such a mathematical model will also have to define the upper possible chronological age for the population on which the method is applied, which is a paradox since the chronological age is unknown.

Statement

Based on this knowledge, the European Society of Paediatric Radiology (ESPR) cannot recommend the use of bone age (estimated using the GP atlas) as a tool for chronological age determination.

References

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