AGE ESTIMATION IN THE LIVING

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Introduction

Determining the actual age of a living individual has great forensic significance, especially in the light of a renewed outbreak of sometimes unlawful adolescent populations (illegal immigration, young people seeking refugee status) and the subsequent rise of delinquency among youths lacking proof of national identity. This may be exacerbated in some countries by a mounting rate of family abandonment or parental death.

Much less frequently, the court may also issue orders aimed at determining the age of adults who, for the most part, are born outside the country and have not been officially registered with the state.

Age Estimation among Children and Young Adults: Justice for those Under Age

Although legislation regulating judicial rules for underage individuals varies from country to country, every judicial system has set up age limits in regard to penal procedures, as well as for penalties applicable to minor delinquents. Thus, the magistrate needs to know the age of individuals involved in penal proceedings.

For example, in France, there are no penal sanctions before the age of 13 years, even when an offense has been committed. Another important age is 16 years because, after this age, prison sentences are more important. The last significant age is 18 years, the age of legal majority.

Age Determination Methods

The estimation of chronological age is derived from the clinical, odontological, and radiological examination findings. Great interindividual variation in all criteria being analyzed commands utmost caution of interpretation and reservations in the final report to the authorities.

Clinical Examination

Anthropometric criteria Anthropometric measurements (e.g., weight, stature) are so highly variable between individuals that they are of little value. It is necessary to rely on easily measurable and replicated criteria such as those found in growth percentile curves. However, such reference groups of boys and girls may not represent all the potential within their generation, and even less so in cases where children are of unknown origin: these results are not then norms, but references to be interpreted.

Sexual maturity criteria Tanner most precisely described normal puberty development in both sexes.

In girls The onset of puberty occurs between the ages of 8 and 13 years. The growth of pubic hair or labia majora precedes puberty by a few months (P2 on the Tanner scale, average $10\frac{1}{2}$ years of age); puberty begins with the development of the nipples (S2 on the Tanner scale, average 11 years). Axillary hair appears during stages S3 and S4 of breast development, about 12–18 months after the appearance of pubic hair (average: 12 years of age). Around 13, menstruation begins, about 18–24 months after the first signs of puberty. The transformation of external genital organs can also be seen: the vulva becomes more horizontal due to forward tilting of the pelvis, and the labia minora develop. Internal organs (uterus, ovaries) also evolve. Other somatic changes are also noticeable: growth of stature, muscular development, and fat deposit on hips and thighs.

In boys Puberty begins between the ages of 9 and 14 years in boys. The onset of puberty begins with modification of the scrotum and penis and enlargement of the testicles, followed by the growth of pubic hair (12 years). In accordance with stages P3 and P4 on the Tanner scale, axillary hair begins to grow (12 – 13 years), later followed by the growth of facial hair between 15 and 20 years. The voice changes around 13–14 years, at stages 4 and 5. Also noticeable are increased growth, broadening of the shoulders (biacromial diameter), and increase in muscular mass.

The evolution of maturity is greatly influenced by genetic and environmental factors, acute diseases that may slow down growth temporarily, and psychosocial factors. Precocious or delayed puberty, whether pathological or not, are eventualities that cannot be excluded on the basis of examination alone. Caution is further warranted since a single secondary sexual trait may remain isolated for a long time without any other sign of development of puberty, without any spurt in stature increase or rate of ossification.

Odontological examination Dental aging may be the most precise method of age estimation, especially before the age of 15 years.

Dental age may be estimated either from the chronology of eruption of the teeth on the gum or from the mineralization of crowns and roots.

A dental formula allows good estimation of age, but, in contrast to the progressive calcification of dental germs, tooth eruption is more influenced by exogenous factors (anatomical characteristics of the maxilla, precocious puberty, heredity, and nutrition).

Chronological age estimation is relatively reliable during childhood, especially with regard to the second molar or "12-year-old tooth" which erupts between 12 and 13 years of age. Eruptions of the deciduous and permanent teeth have a well-known chronology before 15 years of age.

The level of development of crowns and roots is measured from dental X-rays and there are tables that correlate chronological age with the stages of development of crowns and roots. For better results these tables should be adjusted to correlate with ethnic and socioeconomic origins. These methods are more accurate than emergence because they take into account all teeth, even those that are yet to erupt. However the X-ray methods require substantial training and experience to be efficient.

After the age of 15, age estimation is based on the study of the third molar. Odontological methods are still very useful, although the relationship between third molar development and chronological age has been shown to be quite variable. In compensation, age could be estimated until the early 20s. The root begins to develop around the age of 15 and is complete around 21 years, with an average standard deviation of about 2 years. The third molar develops earlier in males than in females, and in mandibular than in maxillary arch. In forensic practice, if the third molar is totally erupted, or the root apices are completely closed, and the periondontal membrane has a uniform width around the tooth, there is a high probability that the chronological age is more than 18.

Alternatively, the third molar may be nonexistent, malformed, impacted, or extracted among young adults. Dental X-rays are very useful in such cases to make a differential diagnosis.

Several methods using computerized images of third molar root growth have been tested but are not currently used.

Bone Age

The evaluation of bone growth is based on the sequence of development of epiphyseal and round bone points of ossification, their growth rate, and the disappearance of cartilage in relation to established reference points.

It is critical to note that the goal of these methods was never to determine chronological age, but rather to evaluate bone development and evolution through time among children presenting with growth defects, to predict adult stature, or to check on the outcome of endocrine treatment.

Bone growth increases during puberty, a period when these tests are most reliable.

Methods There are several methods of determining bone age:

- Quantitative methods require X-rays of half of the skeleton, are very penetrating, and are not often used.
- Qualitative methods are based on morphological variation of centers of ossification for a given articulation, and comparison to pictures of atlas of reference. The Greulich and Pyle atlas is the best known.
- Index methods: a numerical score is attributed to each step of ossification. For each given segment scores are added up to a total number which determines level of ossification.

Greulich and Pyle method This method is based on frontal left-hand wrist and palm X-rays.

The purpose is to identify the carpal bones and the phalangeal epiphyses stage of ossification and compare them to those from the atlas of that particular sex. For both sexes there are reference sources for every 6 months or 1 year, depending on the age. Ossification-based aging is determined by comparing the subject X-ray to the atlas X-ray picture that best approximates it.

The Greulich and Pyle atlas was compiled in 1957 from a population of North American children, born between 1931 and 1942, and in a high socioeconomic stratum.

Bones displayed on each page of the atlas are of the same skeletal age. However, it was demonstrated that, barring any pathology, there could be a time lag between the stage of ossification of the carpal bones and the phalanges of 20 months for boys and 10 months for girls. The differential development of various bones may complicate the selection of atlas X-ray of reference. It is therefore recommended that primacy be given to the fingers.

Studies show that, if the average ossification age is close to the chronological age, standard deviation increases with age (it varies between 4, 7, and 13 months among boys over 17 depending on the study). For European children, the differences found between skeletal ages and chronological ages seem

not to differ from the normal variations in skeletal maturation found initially by Greulich.

With this method, it is commonly accepted that, in order to obtain a reasonable bone age estimation, the result should be presented as an age range which takes into account the atlas pictures before (lower limit) and after (upper limit) the selected one.

A recent study concludes that the Greulich and Pyle method can be used for various ethnic groups. Low socioeconomic status may lead to age underestimation.

Taner and Whitehouse method This method is based on frontal left-hand wrist and palm X-rays.

This is a method based on a specific study of each bone to evaluate the development of certain hand and wrist bones. The first method studies 20 bones (radius, ulna, carpal bones (except the pisiform), and first, third, and fifth finger metacarpal and phalanges). The second method studies 13 bones, RUS (radius, ulna, short bones). Depending on developmental growth, each bone is divided into eight or nine stages. Each stage, documented by picture and diagram, is given a numerical score. The sum of the scores results in a score of skeletal maturation. Numerical results may be combined to obtain three types of skeletal development score: the carpal (TW3) score, the 20-bone (TW3) score, and the RUS (TW3) score. RUS provides the best age correlation, hence should be given priority in calculation.

It is imperative then to relate the chosen skeletal development age score to tables and curves of references to determine the age of ossification.

This method was devised from a population study of Scottish children born in the 1950s from rather low socioeconomic status.

For any given visualization, the difference between the most and the least advanced bone can generate an age difference of 3 months to 1 year. At best, the estimation then gives a variation of ± 6 months.

Differences between various ethnic groups have been observed when age determination is based on the TW2 method. Several methods have generated conversion scales in order to adapt this method to local populations. A more recent atlas is now also available.

An advantage of this "bone-by-bone" method is that the examiner is not influenced by the stages of development of other hand bones.

Other methods The Sauvegrain and Nahum method is based on scoring elbow bones from frontal and profile X-rays. This method is valuable in populations of 11–15-year-old boys and 9–13-year-old girls, and can be a useful complement in forensics when the age is projected to be within this range.

The Risser test is based on a study of the development of the iliac crest points of ossification from a frontal view of the pelvis. The first ossification point appears around 13–14 years in females and 15–16 years in males. Ossification and complete fusion are generally completed in 3 years. Given significant variation in the development of ossification points of the iliac crests and strong potential for irradiation, this test is not systematically performed.

A scan test of the proximal end of the clavicle allows for the determination of four stages approximately separated by 2 years. This method could be used to estimate chronological age up to 29 years, and could be a useful complement to the TW3 and Greulich and Pyle methods.

Computer-enhanced methods Several such methods have been tested, one by Tanner himself: computer-enhanced methods allow for much more rapid analysis. Interobserver and intraobserver variability are greatly reduced. However, the quality of the radiography is critical to avoid important errors. In addition, underexposed or overexposed images that are poorly analyzed by the human eye are not so by the computer. Satisfactory image resolution is necessary, hence the fact that such methods are performed more to estimate bone age after the age of 10.

Computer-enhanced methods assisted by complex mathematical calculation methods called "neural network" have been proposed. Due to the greater precisions of such methods, results have been encouraging so far. Such technology, apparently in the process of being improved, is not currently in application, and these methods are not used in daily practice.

Other Factors

No method truly meets forensic needs.

There are essentially three sources of discrepancy between bone or dental age and chronological age: (1) inter- and intraindividual variability of growth; (2) systematic errors linked to the method itself; and (3) inter- and intraindividual variation among observers. For individuals in good health, skeletal age can be more than 1 year higher or younger than chronological age.

The rate of skeletal growth varies between various ethnic groups and between individuals residing in different countries, but it is the socioeconomic level that seems to play the most important role. Less favorable environments generate growth retardation. Overall, bones mature faster today than in the past. The application of the methods to subjects of unknown origin warrants extreme caution, especially given the fact that the patient's X-rays are never compared to his/her population of reference. National

standards should be established and regularly updated.

If the Greulich and Pyle method is more rapid (and often the only one mastered) and more often used (1.5 mm per picture) than the TW2 (8 mm per picture), studies have shown that it is TW2 that retains the best correlation to chronological age and that offers better reproducibility.

The Greulich and Pyle atlas is the most widely used and has been recommended in practical situations. However, the authors themselves recognize the greater accuracy and reproducibility of the Tanner and Whitehouse method.

Epiphyseal fusion is more subject to population variability and puberty timing than dental development. Thus, dental age will often be closer to chronological age than bone age. Dental age is a more accurate index for age estimation for the early teens. Later in adolescence, only the third molar continues to form. The development of the third molar is quite variable, but allows estimation until the early 20s, whereas bone age, except the clavicle, allows estimation until 18 years of age.

No methods exist to estimate the age of living adults.

In Practice

Chronological age estimation begins with a clinical examination (anthropometric criteria, signs of sexual maturation) followed by odontological examination in order to determine dental status. If all teeth are erupted, including the third molar, it is not necessary to perform radiographs such as orthopantograms. If not, dental radiographs must be performed and interpreted by a forensic odontologist.

Any developmental disorders that may affect normal development should be taken in account.

Radiological bone examination should follow but be limited to a frontal X-ray of the left hand and wrist on the same picture ($\pm$ the elbow if the age appears to be clinically less than 15 years).

The optimal course of action should aim at evaluating bone age from two methods, Tanner and Whitehouse and Greulich and Pyle. In our opinion, the Risser test should no longer be performed. Most often however, one must rely on the Greulich and Pyle atlas, since few trained teams will be able to master the TW3 method.

It is advisable to have a radiologist interpret the X-rays. It is the task of the medical examiner then to synthesize the clinical and radiological results.

In all cases, age estimation will and must be given as an estimation between two value points of discrepancy and should be discussed case by case. The expert must remain wary of puberty retardation and precocity, diseases, and socioeconomic factors that may affect the development of the individual examined.

Conclusion

Age determination is an important and frequent forensic act. The selected method should as far as possible be the most accurate, the most reproducible, and the least irradiating.

The tools at our disposal today can only indicate an age bracket, whereas the court would like to see age determination to the day. Chronological age can only be concluded to a certain degree of likelihood from the biological age, but not definitely determined.

It is necessary for medical examiners to devise new standards and/or to update them on a regular basis, so as to incorporate ethnic, geographic, and socioeconomic differences.

Beyond these requirements, computer-enhanced imaging should take the lead in the future.

See Also

Anthropology: Morphological Age Estimation

Further Reading

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