Learning objectives

1. To review our experience for forensic age estimation in our hospital from 2008 to 2012.
2. Discuss the methods and scientific basis for age estimation.
3. Discuss the limitations and ethical issues involved in age estimation.
4. Discuss how to approach a hand film and construct an accurate report.
5. Illustrate with case studies.

Background

We routinely receive requests for bone age determination. As an adult general hospital, a significant proportion of these requests are for age estimation in judicial cases. We use the Greulich and Pyle Atlas, 1959 to determine the bone age and therefore estimate the chronological age of the person concerned.

Findings and procedure details

Study:

Tan Tock Seng Hospital (TTSH), Singapore is an adult general hospital. It is Singapore's second largest general hospital with over 1,500 beds. The hospital has 36 clinical and allied health departments, 15 specialist centres and emergency and trauma care.

We reviewed the number of cases for bone age determination from 1 Jan 2008 to 31 Dec 2012. There were a total of 58 cases for bone age determination. Of these, 29 cases (50%) were for medical reasons, such as endocrine abnormalities, and 28 (48.3%) were judicial cases. The indication for 1 case was unknown.

Table 1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Judicial</th>
<th>Non-Judicial</th>
<th>Unknown</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>14</td>
<td>3</td>
<td>0</td>
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<tr>
<td>2009</td>
<td>5</td>
<td>7</td>
<td>1</td>
<td>13</td>
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The judicial cases were cases involving suspected illegal immigrants and criminals. We therefore performed an average of 5.6 (approximately 6) cases per year for forensic age estimation between 2008 and 2012.

**Definition:**

Forensic age estimation defines the expertise which aims to determine in the most accurate way possible the chronological age of a person of an unknown or doubtful age involved in judicial or legal proceedings.

Persons with unknown or doubtful age may include immigrants, refugees or criminals.

**Forensic age estimation (FAE):**

Currently there is no single medical test or group of tests that absolutely and accurately let us know the exact chronological age of a human being (Ritz Timme et al, 2000). Different countries use different test or group of tests. The uncertainty of age may arise due to circumstances. In some countries such as Afghanistan, calendars are banned. The chaotic circumstances surrounding the time of birth, such as during war, may contribute to a lack of registration of the birth or lost of registration papers. The child may be separated from the parents and therefore making the determination of age uncertain. Other possibilities may include an adopted child or administrative error.

Another situation is wilful falsification of birth data e.g. in order to gain entry to a country, or when charged for criminal offence.

If exact date of birth is unknown, most authorities arbitrarily record a birth date of 1 January.

**Tests for FAE:**

Tests for FAE may include:
- Physical examination

- X-ray tests

- Psychological interview

A psychological interview may be performed to evaluate the social maturity; whether the social maturity is consistent with the reported age.

**Physical examination:**

Age estimation may include a physical examination, such as determination of the height and weight, and sexual maturation. Physical examination is also important to exclude any underlying pathology or disease.

Physical maturation is established by comparing the height and weight of the person and match to growth charts.

Sexual maturation can be determined by examining for facial, axillary and pubic hair, laryngeal prominence and the stage of development of the penis and testis in males and the breasts in females.

The most widely used method for determining sexual maturity is based on sexual staging by Marshall and Tanner (1970).

Age determination by physical and sexual examination is an inexact science. There can be a margin of error of plus or minus 5 years (Levenson et al, 1999).

**X-ray tests:**

X-ray tests may include:

- X-ray of wrist and hand

- Orthopantomogram (OPG) to evaluate dental maturity

- X-ray or CT of clavicle.

**X-ray of the hand:**
Tests that use x-ray of the wrist and hand are based on studies and standards such as those established by Greulich and Pyle (published in 1950 and 1959), Tanner and Whitehouse (1983) and Thiemann and Nitz (2006).

Greulich and Pyle:

Greulich and Pyle first published their Radiographic atlas of skeletal development of the hand and wrist in 1950 and the second edition in 1959. This is based on a sample of almost 7,000 healthy children, of middle to upper class economic status (that is, above average in economic status). These are North American children; white and of North European ancestry. The study was carried out in the 1930s-1940s.

The left hand was used for the radiographs. The International Agreement for the Unification of Anthropometric Measurements to be made on Living Subjects drawn up at the Monaco and Geneva Conferences of Physical Anthropologists in 1906 and 1912, respectively, specified that measurements be made of the left rather than the right side of the body and of the left extremities. Another consideration was the fact that most people are right handed. The right hand is more often injured and therefore the left hand is more likely to be intact.

Discrepancies between the left and right hand are too insignificant to constitute a source of error (Dreizen, 1957).

Greulich and Pyle atlas can be used to determine the skeletal or bone age as well as predict adult height.

Tanner and Whitehouse:

Tanner-Whitehouse charts were originally based on the Oxford Health Survey started by John Ryle in the 1940s. Measurement data of the carpus were analysed by Roy Acheson. The investigators applied a maturity score for each bone. A final maturity score was determined. Tanner published it in 1983.

Therefore, there are primarily two methods to estimate bone age based on carpal bones; the Atlas method by Greulich and Pyle, and the Numerical method by Tanner and Whitehouse.
The numerical method by Tanner and Whitehouse is in theory more accurate but in practice difficult to apply and use, and difficult to be consistent. The atlas method by Greulich and Pyle is easier to use in practice.

Complete fusion of epiphysis of hand and wrist occurs at approximately 18 years of age (18 for female, 19 for male).

So what is the normal range of variation from the chronological age?

If there are more than 2 standard deviations (SD) from the mean, there is a high probability that growth is abnormally retarded or accelerated.

As a rule of thumb, a variation of approximately 1 to 2 years in a teenager may be within the range of normality.

**Dental x-ray:**

There are tests based on dental analysis. These tests are based on studies by Demirjian (1976) who published the Dental maturity scale, Nolla (1960) and others.

Dental analysis can involves the evaluation of mineralization of tooth crowns, eruption of the molars including the third molar, and evaluation of volume of pulp.

One of the systems most universally used to evaluate the degree of dental development is that by Demirjian (Demirjian et al, 1973, 1976). This system evaluates the degree of calcification of the teeth in the left hemimandible and the determination of a dental maturity score.

An OPG is generally performed.

**Clavicle x-ray:**

The clavicle can be used to estimate bone age. This is by evaluating the medial epiphysis of clavicle.
To answer whether a person has reached the age of 18, it is helpful to evaluate the ossification status of the medial epiphysis of the clavicle because all other skeletal system may have already completed their growth.


Fig. 1 on page 13 Schematic drawings and pictures of the stages 1-5 of clavicular ossification as revealed by conventional radiography (CR) and computed tomography (CT).

Stage 4 is when the epiphyseal plate is fully ossified but the physeal scar is visible. This occurs at 20 years for women and at 21 years for men.

Stage 5 is when the physeal scar is not visible. This occurs at 26 years for both sexes.

The chest x ray is often good enough to evaluate the clavicular epiphyses; if not, oblique views of the clavicle may be performed.

Clavicular epiphysis can also be evaluated with ultrasound or MRI to avoid ionising radiation.

**Combined or multifactorial method:**

The Study Group on Forensic Age Diagnosis (AGFAD) was founded in Berlin in 2000. It published guidelines on age diagnosis on living individuals for criminal, civil and asylum proceedings. They advocate a multifactorial method that includes:

- Medical examination
- Dental x-ray
- X-ray of the hand
- Psychological interview
- X-ray of the clavicle is performed if the estimated age is at least 18 years.

In combined methods, e.g. dental age plus bone age, the lowest age should be used because of ethical and legal reason (AGFAD, 2001, Garamendi et al, 2005).
Pathological conditions:

It is important to remember that bone age may be affected by diseases and medical conditions.

Bone age may be retarded in diseases or conditions such as:
- Anaemia
- Thalassemia
- Diabetes mellitus
- Hypogonadism
- Fetal rubella syndrome
- Trisomy 21
- HIV
- Elite sports

Bone age may be advanced in diseases or conditions such as:
- Adrenal hyperplasia
- Cushing Syndrome
- Gigantism
- Hyperthyroidism
- Precocious puberty

Most diseases delay development and leads to underestimation of the age. Such underestimation usually do not disadvantage the person concerned in the judicial framework.

However diseases that accelerate skeletal development may lead to overestimation of the age. This should be avoided especially in judicial cases.

Ethical questions:

The exposure to radiation without medical indication has been a concern of medical and human rights groups.

The following are the effective dose of different x-ray procedures (Rammstahler et al, 2009):
- X ray hand 0.1 uSv (0.01 mSv)
- OPG 26 μSv (2.6 mSv)
- Background radiation 2.0 mSv/year
- Flight crew 2000 mSv/year

On the basis of comparison with background radiation and exposure of flight crew, it is felt that x-ray exposure for FAE is negligible (Schmeling, 2008).

**Ethical dimension of expert report and possible errors:**

Physicians involved in writing expert report must be cognisant of the ethical dimension of their conclusion.

Expressing expert opinion in the Court of Justice should be cautious because there is no solid scientific basis of the references.

The Greulich & Pyle reference was designed as a tool to assess the physical development of children. That is, whether a child physical development is retarded or accelerated compared to his presumed accurate chronological age, and not to determine chronological age.

When used to determine the chronological age, the degree of error is unknown.

Possible errors from reference data may be due to several factors including:

- Genetic
- Race
- Geography
- Environment
- Socio-economic factor

Stress such as encountered by refugees from war zone, socio-economic conditions and nutrition may affect physical development and bone age.

The Greulich and Pyle data are from a different era.
Any underlying disease will also cause errors.

There are studies conducted in the 1970s and 1980s studying the bone age of Chinese and Japanese groups. These studies found that the bone age was delayed with respect to chronological age during pre-pubertal period but there was accelerated growth during post pubertal period. The final bone maturity reached was at a similar age for European and American groups (Schmeling et al, 2011).

Studies on Negroid subjects however showed contradictory results. Study on Black Jamaicans showed delayed bone age compared to TW standard (Marshall et al, 1970). Another study showed no significant difference between the bone age and chronological age (Gilsanz et al, 1988).

A study on an Indonesian population (Jahari el al, 2000) showed significant delay in bone age due to socio-economic factor and poverty.

Most studies on major ethnic groups showed no significant difference.

It is generally possible to apply the reference data without significant differences (Schmeling et al, 2001).

The most important source of possible error was felt to be socio-economic factor and poverty. This usually leads to underestimation of the age. Such underestimation usually do not disadvantage the person concerned in the judicial framework.

**Expert report:**

A radiologist may be called upon to give expert opinion on the age of a person in a judicial case.

While expressing with confidence will help judges make decision more easily, this is however not advisable as it may give the Court a false impression of certainty.

In writing the expert report, the reference studies should be mentioned e.g. Greulich and Pyle 1959. The use of word or phrase such as "estimated" age or "most likely" age may be appropriate.

So how accurate is it?
Based on the Atlas of Greulich and Pyle 1959, a variation of plus or minus 2 SD for margin of error is generally accepted.

There is yet no satisfactory way to scientifically determine the margin of error.

It is important to remember that the Greulich and Pyle atlas was designed as a tool to assess the physical development of children i.e. whether a child physical development is retarded or accelerated compared to his known chronological age and not to determine their chronological age.

The radiologist should also be aware of confounding factors e.g.

- Racial
- Socioeconomic
- Data was obtained some 70 years ago
- Any underlying disease

**How to assess a Hand Film:**

2. Compare film with adjacent older or younger standards.
3. Find the standard which superficially resemble most closely to the film.
4. Conduct detailed analysis of the epiphyses systematically, e.g. from the radius/ulna to the carpus, to the metacarpals and then to the phalanges.

**Case Study 1:**

A domestic maid was convicted for strangling her 87-year-old employer. She was sentenced to 20 years in prison on a charge of culpable homicide not amounting to murder.

Her passport and work-permit stated that she was 23 years old. These documents were suspected to be false.

**Fig. 2** on page 13 The accused
An x-ray of her hand estimated her age to be 17 years.

**Fig. 3 on page 14 Accused's left hand x-ray**

The accused lawyer argued that a jail term of between 8 and 10 years was more appropriate due to his client’s young age and immaturity.

Further investigations corroborated with the bone of age that suggested she was younger than 23 years. She was subsequently shown to be 16 years and 11 months old when she left home to work in Singapore.

Her lawyer said in her mitigation that her father had falsified her age to 23 years in order for her to work in Singapore. Singapore labour law requires domestic maid to be at least 23 years old in order to work in Singapore.

Her jail term was subsequently reduced to 10 years.

**Case study 2:**

This person is a male arrested for illegal entry into the country. According to his statement, he was 17 years 5 months at the time to arrest. He did not have proper or valid travel documents. An x-ray of the left hand was performed to estimate his age. The x-ray estimated his age to be 14 years.

**Fig. 4 on page 16 Suspect's left hand x-ray**

According to the Radiographic atlas of skeletal development by Greulich and Pyle (1959), the bone age of this suspect most closely matches the male standard of 14 years.

The chronological age of this person at the time of performing the left hand radiograph was 17 years 5 months. The 2 SD of a boy of this age ranges from 15 years 3 months to 19 years 7 months.

The bone age is below the 2 SD range from the chronological age. Assuming there is no underlying disease that may delay the bone age, the person is most likely younger than his stated chronological age.
Fig. 1: Schematic drawings and pictures of the stages 1-5 of clavicular ossification as revealed by conventional radiography (CR) and computed tomography (CT).
Fig. 2: The accused
**Fig. 3:** In the radius, fusion of the epiphysis is almost complete. The rest of the epiphyses in the wrist and hand are fused. According to the Radiographic atlas of skeletal development by Greulich and Pyle (1959), the bone age most closely corresponds to the female standard of 17 years.
Fig. 4: The x-ray shows that the physes of the radius and ulna have not fused. The epiphysis of the radius has begun to cap the shaft. The epiphyses of the metacarpals show late pre-fusion stage. The epiphyses of all the phalanges of the 2nd to 5th fingers have begun to cap their shafts. The epiphyses of the distal phalanges have not fused yet. According to the Radiographic atlas of skeletal development by Greulich and Pyle (1959), the bone age most closely matches the male standard of 14 years.
Conclusion

Forensic age estimation is often part of the work of a radiologist in a general hospital. It is important to understand the methods used, the limitations of these methods and the medico-legal impact. Constructing an accurate report is important because the radiology report may affect the outcome of the judicial case.

Personal information

References


