Age assessment by the Greulich and Pyle method compared to other skeletal X-ray and dental methods in data from Finnish child victims of the Southeast Asian Tsunami

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Abstract The validity of the age assessment method based on the “Radiographic Atlas of Skeletal Development of the Hand and Wrist” by Greulich and Pyle (1st edition 1950) has been frequently questioned. The purpose of this study was to examine the reliability of this widely used method and to compare it to various dental and other skeletal age assessment methods. Forty-seven Finnish children of known ages below 16 years, who perished in Thailand in the Southeast Asian Tsunami on 26 December 2004 were examined. Every victim repatriated to Finland underwent a complete forensic autopsy including CT-scan, toxicological screening, and diatom analysis in order to establish the cause of death, as well as DNA testing and dental examination for the verification of the identification established in Thailand. Age assessment was performed by dental and skeletal methods. The average difference between the age assessment values obtained by the Greulich and Pyle method, and the chronological age was 9.7 months. In addition to the Greulich and Pyle method, an alternate skeletal method, Tanner and Whitehouse 2, resulted in an average age difference of 10.3 months. Dental age assessment methods were based either on the eruption (Nystroem method, 8 cases, average age difference 5.6 months), or the development of the crown and roots (Demirjian method, 33 cases, average age difference 5.2 months and ABFO method, 7 cases, average differences 12.6 months). Dental methods proved to be most accurate in childhood until the teeth—except the wisdom teeth—have erupted and root development is completed. In adolescence, however, the validity of skeletal methods improves considerably.

Keywords Dental identification · Greulich and Pyle · Skeletal identification · Age assessment · Tsunami

Introduction

For numerous forensic investigations of both living or dead individuals, the knowledge of the correct age or date of birth of the subject is of utmost importance. The need for assessment of age of living persons has increased in recent years, particularly in cases where an individual does not have reliable documentation and is seeking asylum or refugee status, or has applied for a benefit from society (e.g. a pension). In the identification of a deceased individual, the result of age assessment together with other post mortem findings has to be in concordance with ante mortem data, and may particularly aid in identification processes in mass disasters.

Various biomedical, dental and anthropological methods have been developed to assess the age of an individual. These methods have been based either on the skeletal or dental status of the individual in question. In 1950 Greulich and Pyle published their classical work “Radiographic Atlas of Skeletal Development of the Hand and Wrist” [1], which has been widely used as a reference for age assessment. However, since the data of Greulich and Pyle were studied as early as 1931–1942 and derived from one thousand Caucasian children, it has been questioned whether the original standards are still valid for different populations. According to Loder et al. [2], the Greulich and Pyle (G-P) method appears to be less reliable for black girls; Ontell [3] observed differences in the maturation rate.
between diverse ethnic groups (white, black, Asian, Hispanic); while van Rijn (2001) showed that the G-P method is still useful for Dutch Caucasian children [4].

The purpose of our study was to evaluate the applicability of these standards to contemporary Finnish children. The study included age assessments by different skeletal and dental methods of the victims of the Southeast Asian Tsunami on 26 December 2004, identified in Thailand and re-examined in Finland. Besides complete forensic autopsies, examinations also included DNA testing and dental examination for the verification of the identification established in Thailand. The dental post mortem investigation and age assessment were performed to aid the identification process. The skeletal age assessment was also performed from digital X-rays taken from the hands and wrists.

Materials and methods

The Southeast Asian Tsunami on 26 December 2004 claimed 5,395 victims in Thailand. Of these, there were 2,436 foreign nationals including 178 from Finland. Many of the victims were children celebrating Christmas holidays with their families. The number of Finnish children under 18 years of age was 56. One-third of all victims were children due to the high proportion of them among the local population and their inability to swim or physically resist the forces caused by the surging water and floating material.

For collection of dental ante mortem data, principal dental officers of the five major cities and all appr. 4,800 practicing dentists in Finland were approached by post and e-mail with the list of missing persons and a request to search their patient files. Documents of only four persons (2.2%) remained missing including two infants, a middle-aged and an elderly edentulous male.

In the medical ante mortem data received from relatives, health care centres, and hospitals, no information of diseases affecting skeletal growth or maturation was available.

Under Finnish law for the investigation of the cause of death [5] all 165 victims found and identified in Thailand, and repatriated to Finland, underwent a complete forensic autopsy in Finland, including CT-scan, toxicological screening, diatom analysis in order to establish the cause of death, and DNA testing and dental examination for the verification of the identification established in Thailand.

Autopsies also included digital X-rays of the whole body and in 56 cases of children under 18 years, radiographs of the hand and wrist were taken using Siemens Multitix CPH. The dental identification included a panoramic tomogram or, if not possible due to injuries, periapical X-rays. The age assessment for the identification was performed using dental methods based either on the clinical eruption or development of teeth.

The quality of each age estimation was ensured, and potential inter-examiner differences or training effects minimized, by using only odontologists with experience from previous DVI-processes, and having a formal subspecialization in forensic odontology provided by the Finnish Odontology Society. To further ensure high quality examinations, two experts independently reported their findings.

Skeletal age assessment methods

The age assessment based on G-P method could, due to destruction of hands, be performed only in 47 cases, including 23 girls and 24 boys. The study was based on the second edition of the Greulich and Pyle Atlas, published in 1959 [1]. The G-P study was performed independently by two specialized forensic odontologists. The assessment results were compared, differences were discussed, and differing cases re-examined together.

The injuries of fingers in 13 victims limited the assessment by RUS (Radius, ulna and shortbones), and 20 bones method [6] to 34 individuals. The age distribution of the children is shown in Table 1.

Dental age assessment methods

This method, based on tooth eruption, required counting of the number of deciduous or permanent teeth with comparison of results to tables of Finnish reference values [7, 8]. However, this method could be applied to only eight cases due to the decomposition of soft tissues.

The Demirjian method [9] was the most frequently used method, involving 33 cases. It is based on the developmental status of seven permanent mandibular teeth on the left side. Problems in nine cases were caused by missing teeth due to the post mortail decay of soft tissue around the teeth, or extractions for dental DNA analysis.

Table 1 Age distribution of the Finnish child victims of the Southeast Asian Tsunami on 26 December 2004

<table>
<thead>
<tr>
<th>Age</th>
<th>Female</th>
<th>Male</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–2.9</td>
<td>0</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3–5.9</td>
<td>10</td>
<td>4</td>
<td>14</td>
</tr>
<tr>
<td>6–8.9</td>
<td>5</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>9–11.9</td>
<td>4</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>12–14.9</td>
<td>6</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>15–17.9</td>
<td>4</td>
<td>3</td>
<td>7</td>
</tr>
</tbody>
</table>
In seven cases the method used was ABFO (American Board of Forensic Odontology, Mincer, 1993), based on the development of third molars (wisdom teeth) [10].

Statistical treatment of the data

The reliability of age assessment methods, except ABFO with seven cases, was tested with Intraclass Correlation Coefficient using the SPSS program 15.0 for Windows (Table 3).

Results

Skeletal age assessment methods

Assessments using the method of Greulich and Pyle showed that the chronological age exceeded the skeletal age in 13 cases, was below in 10, and was the same in 1 case in boys. In girls, the chronological age exceeded the skeletal age in 13 cases, was below in 9, and was the same in 1 case (Fig. 1). No significant differences existed between the results in boys and girls, or between different age groups as demonstrated in Fig. 2 (difference in months). On average, for the boys and girls together the difference between the chronological age and estimated age was 9.7 months (Table 2). However, the relative difference was greater in younger children as shown in Fig. 3.

The TW2 [6] method consists of three parts including the carpal bone method, the RUS method and the 20 bones method. The last one used in this study—a combination of carpal and RUS methods—differed by 10.3 months from the chronological age.

Fig. 1 Greulich and Pyle age assessment results of boys and girls

Fig. 2 Difference of the Greulich–Pyle age assessment values in relation to the chronological age. Difference (D) (in months) is calculated using formula: $D = \text{Age}_{\text{chronological}} - \text{Age}_{\text{assessment value of Greulich and Pyle}}$

Table 2 Age assessment by various methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Average differencea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skeletal</td>
<td></td>
</tr>
<tr>
<td>Greulich and Pyle</td>
<td>9.7</td>
</tr>
<tr>
<td>TW2, 20 bones</td>
<td>10.3</td>
</tr>
<tr>
<td>Dental</td>
<td></td>
</tr>
<tr>
<td>Eruption</td>
<td>5.6</td>
</tr>
<tr>
<td>Demirjian</td>
<td>5.2</td>
</tr>
<tr>
<td>ABFO</td>
<td>12.6</td>
</tr>
</tbody>
</table>

The average deviation from the chronological age

a Difference is given in months
The method of Nyström [7, 11], based on the eruption of deciduous or permanent teeth, was the method of choice for young children in eight cases. The difference between the chronological age and estimated age was on average 5.6 months.

The Demirjian method [9], applied to 33 cases, resulted in the difference of 5.2 months between the chronological and estimated age.

The third molar method by Mincer et al. [10], based on the development of wisdom teeth is the only dental method to use in late adolescence. In seven examinations the difference between the chronological and estimated age was on average 12.6 months.

No concordance existed between the results of skeletal and dental methods. For example, a case that was 24 (G-P) and 30 (TW2) months higher than true values by skeletal methods, had the exact age estimated by the Demirjian method. The maximum difference by the Demirjian method was 17 months higher than the chronological age. The same case assessed by G-P differed by 29 months, and was 21 months higher by the 20 bones method. The result with the greatest deviation in the method based on eruption of permanent teeth was 16 months below the chronological age, while the difference by the G-P method was 10 months, and by TW2, 11.5 months. The ABFO method (only 7 cases) showed the most frequently higher age estimates than the chronological age and skeletal estimates.

In another example, the skeletal ages of a boy (8.4 years) and his sister (4.9 years) appeared to be delayed by 17 months. The dental age, however, did not show such marked divergences (5 and 0 months).

The smallest deviation from the chronological age (Fig. 4) and highest Intraclass Correlation values occurred in the results from the dental methods based on eruption (Nyström), and development (Demirjian), having average values of 0.990, and 0.994, respectively (Table 3).

**Discussion**

The choice of the most appropriate method for age assessment is dependent on the developmental stage of a child. For very young children the most successful choice may be to count the erupted deciduous teeth. According to the specific weighted scores of Demirjian method for Finns
Table 3 Reliability analysis of age assessment methods

<table>
<thead>
<tr>
<th>Method</th>
<th>ICa</th>
<th>95% CIb</th>
<th>LBc</th>
<th>UBd</th>
</tr>
</thead>
<tbody>
<tr>
<td>All dental methods</td>
<td>0.993</td>
<td>0.987</td>
<td>0.992</td>
<td></td>
</tr>
<tr>
<td>Greulich-Pyle (skeletal)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single measure</td>
<td>0.969</td>
<td>0.944</td>
<td>0.982</td>
<td></td>
</tr>
<tr>
<td>Average measure</td>
<td>0.984</td>
<td>0.971</td>
<td>0.991</td>
<td></td>
</tr>
<tr>
<td>TW2, 20 bones (skeletal)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single measure</td>
<td>0.962</td>
<td>0.925</td>
<td>0.981</td>
<td></td>
</tr>
<tr>
<td>Average measure</td>
<td>0.981</td>
<td>0.961</td>
<td>0.990</td>
<td></td>
</tr>
<tr>
<td>Demirjian (dental)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single measure</td>
<td>0.988</td>
<td>0.976</td>
<td>0.994</td>
<td></td>
</tr>
<tr>
<td>Average measure</td>
<td>0.994</td>
<td>0.988</td>
<td>0.997</td>
<td></td>
</tr>
<tr>
<td>Eruption (dental)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single measure</td>
<td>0.979</td>
<td>0.924</td>
<td>0.995</td>
<td></td>
</tr>
<tr>
<td>Average measure</td>
<td>0.990</td>
<td>0.960</td>
<td>0.997</td>
<td></td>
</tr>
</tbody>
</table>

Interclass correlation with the chronological age is calculated using one-way random effects model where people effects are random


[12], the maturation of dentition (28 teeth) ends at the age of 16 years in boys, and 15.8 years in girls (50th percentile). The maturation of third molars finishes around 20 years. The rate of maturation of the wisdom teeth is irregular both between and within individuals. According to the study of the ABFO, asymmetry of maturation exists both between the left and right sides, and between the mandible and the maxilla. The G-P method is used until the age of 19 years in boys and 18 years for girls as the reference X-rays show the final stages of the maturation of the bones of the hand and wrist [1]. Certain authors such as Kreitner et al. [13] have used age assessment methods based on the ossification of the medial extremity of the clavicle and claim it to be valid up to the age of 27 years. Similar to the present study, comparison of dental and skeletal age estimations with the chronological age has been performed by Bhat and Kamath [14] who found correlation coefficients (R) of 0.75 and 0.85 for the right and left mandibles, respectively, to the skeletal age, and 0.92 of skeletal maturity with chronological age.

The children examined in this study lived in different parts of Finland, with most coming from the South. Based on the means to travel to Thailand, the families were possibly above average in socio-economic status. However, medical and dental health care in Finland is based on the Primary Health Care Act 66/1972 [15] which states “primary health care means health care addressing individuals and their living environment, medical care for individuals, and related activities aimed and maintaining and promoting the state of health of the population”. Thus, the health care of children is independent of the socioeconomic status or the place of residence.

Differences of opinion exist as to whether modern children mature physically earlier than in previous decades. Some investigators studying the validity of the G-P method assume this to be the case [2, 16]. However, according to van Rijn [4] the bone maturation itself has not changed, although adult height has increased significantly in Dutch children.

Regulation of the rate of the pubertal, skeletal and dental development is genetically mediated by hormones. Estrogen, formed through aromatization from testosterone, regulates the epiphyseal fusion of the long bones in both genders. Final height has been attained when the epiphyses of the long bones are completely closed. Pubertal matura
tion is mainly regulated by the hypothalamic-pituitary-gonad axis. Variations exist in the rate of skeletal development between individuals and populations. Environmental factors like qualitative or quantitative deficiency of nutrition may retard the rate of sexual maturation and growth in height. In Finland height has increased by approximately one centimetre per decade during the last century until the 1970s [17]. No disruptive factors existed for the development of the skeleton in the test group of Greulich and Pyle, since the children were healthy and lived in good socioeconomic conditions. Since the development of dentition is not readily affected by environmental factors or diseases, it may be a reliable object in comparing racial differences. Chaillot and co-workers observed variations in the rate of dental maturation between different populations [8].

It should be emphasized that the use of ionizing radiation for non-medical purposes is strictly regulated in the European Union (EU). In Finland, the Radiation Protection Authority has issued a special permit to the Department of Forensic Medicine of University of Helsinki allowing the use of x-rays for age assessment. In their “Letter from American Leaders in Dentistry, Medicine and Psychology Expressing Concern Over Irresponsible Age Determination Practices Affecting the Lives of Young Immigrants, Including Asylum Seekers”, 73 experts recommend the announcement of the United Nations High Commission for Refugees that age assessment “should take into account not only physical appearance, but also psychological maturity”, and that children “should be given benefit of the doubt if the exact age is uncertain” [18].

The results of skeletal age assessment methods compared to the chronological age, and with the results of age assessment by teeth, do not differ so much as to be
considered unreliable. The mean difference between the skeletal and chronological age was less than 1 year. However, we are aware that our dataset was limited, and therefore the results should be interpreted with caution.

Due to the simple method and illustrative X-rays the results are reliable even if the examiner is less experienced. In the protocol used, we took into account the inter-examiner difference in the measurements and subsequent age estimation. The difference between the results of two forensic odontologists was on average 0.6 months.

If there is a good reason to perform an X-ray based age assessment on a living person, a dental one may be recommended, at least until adolescence. The radiograph, for example a panoramic tomogram, is also usable for odontological reasons showing the condition and the stage of development of the dentition. Obviously, if the question is of a deceased individual, dental X-ray status can also be used for identification.

Key points

1. Data collected in the investigation of human loss in natural catastrophes, such as the Southeast Asian Tsunami on 26 December 2004, can be used to make scientific analyses on issues that are otherwise difficult to derive conclusions from. Age assessment, as analysed here, is one example.

2. Dental methods proved to be more accurate in childhood compared to skeletal methods, until the teeth (with the exception of wisdom teeth) have erupted and root development completed.

3. This study puts the widely used Greulich and Pyle method into a critical light.

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References


