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ORIGINAL ARTICLE

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Reference data for the Thiemann–Nitz method of assessing skeletal age for the purpose of forensic age estimation

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Abstract The aim of this study was to determine the statistical parameters of deviation in the Thiemann–Nitz method for use in forensic age diagnostics. To this effect, 402 hand radiograms, originally taken in two large German cities between 1983 and 2002 for the purpose of diagnosing trauma, were analyzed. At the time of examination, the patients were aged between 10 and 18 years. The study presents the mean, standard deviation, and median, with lower and upper quartiles, for the skeletal ages of 11.0 through 18.0 years. The simple standard deviations range between 0.2 and 1.2 years. To increase the accuracy of age estimates and improve the identification of age-relevant developmental disorders in forensic age estimation practice, the methods for determining skeletal age should always be combined with a physical and dental examination. In addition, the expert opinion should pay attention to the issue of different modernization levels in relevant populations.

Keywords Forensic age estimation · Skeletal age · Hand ossification

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Introduction

Recent years have brought a worldwide increase in cross-border migration due to a globalized economy, European integration, and ongoing belligerent conflicts. As a result, the number of foreigners who cannot provide documentary evidence for their date of birth has increased not only in Germany, but also in numerous other European countries. Because of this development, forensic age estimation of live subjects has increasingly become an integral part of forensic practice. Similarly, forensic age diagnostics now constitute a growing field within legal medicine [9–11, 16, 18].

Usually, the individuals subjected to forensic age estimation procedures are foreigners without valid identification documents who are suspected of making false statements about their age and whose genuine age is of legal relevance. In Germany, the age thresholds relevant for legal purposes are 14, 16, 18, and 21 years [7]. Similarly, the legally relevant age limits in numerous other European countries range from 14 to 18 years of age [3].

To estimate the age of a person as part of criminal proceedings, the international interdisciplinary Study Group of Forensic Age Diagnostics (http://www.charite.de/rechtsmedizin/agfad/index.htm) recommends combining a physical examination, an X-ray of the hand, a dental examination which records dentition status and evaluates an orthopantomogram, and an X-ray or CT scan of the clavicles [14]. One of the main criteria used in forensic age diagnostics is, therefore, the developmental status of the hand bones.

To evaluate the form and size of individual bone elements and the degree of ossification of the epiphysial plates, either a given X-ray image is compared with standard images of the relevant age and sex (radiographic atlas) [5, 21] or the degree of maturity or bone age is determined for selected bones (single bone method) [12, 19, 20].

Various studies have demonstrated that although the single bone method requires more time, it does not necessarily yield more accurate results [1, 2, 8]. Hence, the radiographic atlas methods developed by Greulich and Pyle [5] and by Thiemann and Nitz [21] seem to be suitable for forensic age diagnostics.

The present work is the first to present reference data for the Thiemann–Nitz method for skeletal age assessment that can be used for forensic purposes.

Materials and methods

The study analyzed 402 hand radiograms, originally taken at a number of Berlin and Leipzig hospitals from 1983 to 2002, for the purpose of treating injuries.

At the time of the X-ray examination, the patients were aged between 10 and 18 years. Table 1 shows the number of cases included in the analysis of X-ray images, separately for both sexes and for all age groups.

Overall, 164 X-ray images of the left hand and 238 of the right hand were available.

No information was available on the ethnic origin of the subjects examined. As this population was a random selection of patients, there is no reason to believe that the population differs greatly from that of the average German population.

The radiographic atlas method developed by Thiemann and Nitz [21] was used for determining the skeletal age.

Results are expressed as mean±standard deviation (SD) and median with lower and upper quartiles. Statistical analysis was performed using SPSS for Windows (Release 11.0.1, SPSS Inc., Chicago, IL, 1989–2001). Because of limited sample size or nonsymmetrically distributed observations, differences between the right and left hand were analyzed using nonparametric statistical tests (Wilcoxon test for paired observations). Exact versions of the tests were applied to handle major differences in sample sizes (StatXact 5, Cytel Software Corp., Cambridge, MA, 2001). Significance was assessed at $p<0.05$, exact, and two-sided.

Results

Table 2 presents the mean±SD and median with lower and upper quartiles for all skeletal ages from 11.0 to 18.0 years separated by sex. Because of insufficient sample size, no statistical measurement data were computed for the skeletal ages 10.0 and 10.5 years.

Table 1 Number of cases by age and sex

Age (years)	Male	Female
10	19	19
11	22	13
12	30	24
13	32	17
14	31	15
15	29	23
16	24	23
17	24	14
18	30	12
Total	242	160

Results are not presented separately for the left and right side, since no statistically significant differences between sides were found.

For the age group under examination, the simple standard deviations of mean values range between 0.2 and 1.2 years.

Discussion

Radiographic atlas method of Greulich and Pyle [5] is the most commonly used method worldwide for determining skeletal age. They developed their X-ray standards based on the hand radiograms of the Brush Foundation longitudinal study, which covered the period from 1931 to 1942, and examined 1,000 Americans of northern European descent living in Cleveland, OH, aged between 0 and 18 years. For each age group, the most representative X-ray image was chosen out of 100.

The radiographic atlas presented by Thiemann and Nitz [21] is based on a considerably more recent sample. In the German Democratic Republic in 1977, using a standardized study design, 20 medical institutions produced and analyzed 5,200 hand X-rays taken of subjects aged between 0 and 18 years.

Table 2 Statistical parameters (in years) by sex for skeletal ages 11.0–18.0 years

SA (years)	Sex	Mean±SD	Median, LQ and UQ
11.0	Male	11.4±0.6	11.5, 10.9, and 12.0
	Female	10.7±0.6	10.5, 10.1, and 11.3
11.5	Male	11.2±0.5	11.2, 10.7, and 11.7
	Female	10.8±0.2	10.7, 10.6, and 11.0
12.0	Male	12.1±0.6	12.0, 11.6, and 12.6
	Female	11.1±0.7	11.0, 10.4, and 11.6
12.5	Male	11.8±0.9	11.8, 11.3, and 12.3
	Female	12.0±0.7	12.1, 11.5, and 12.5
13.0	Male	12.5±0.9	12.5, 11.8, and 13.3
	Female	11.8±1.2	11.6, 10.8, and 13.0
13.5	Male	13.2±0.8	13.0, 12.6, and 13.4
	Female	13.6±1.2	13.4, 12.5, and 14.5
14.0	Male	14.3±0.8	14.3, 13.8, and 14.8
	Female	13.9±1.2	13.6, 13.3, and 14.2
15.0	Male	14.9±1.2	14.6, 14.3, and 15.5
	Female	14.8±0.9	14.5, 14.3, and 14.8
16.0	Male	15.3±0.8	15.1, 14.9, and 16.3
	Female	16.0±0.8	15.9, 15.5, and 16.6
17.0	Male	16.8±1.1	16.8, 15.9, and 17.8
	Female	17.5±0.8	17.7, 16.8, and 18.1
18.0	Male	18.2±0.7	18.5, 18.1, and 18.7
	Female	18.1±0.6	18.0, 17.5, and 18.7

SA Skeletal age, *LQ* lower quartile, *UQ* upper quartile

It was possible to use the Thiemann–Nitz method [21] for forensic age diagnostics only to a limited extent, since their radiographic atlas did not indicate the statistical parameters of deviation for the individual skeletal ages.

This study measures the range of deviation for the Thiemann–Nitz method for the first time. In our study, the simple standard deviations range between 0.2 and 1.2 years. For their method, Greulich and Pyle [5] determined a simple standard deviation of 0.6 to 1.1 years in the relevant age group. Johnston and Zimmer [6] presented comparable results for the Greulich and Pyle method.

In age estimation practice, additional examination methods help reduce the range of deviation. For example, skeletal age determination methods should always be used in combination with a physical and dental examination [14]. So far, it has not been possible to present a statistically verified range of the combined age diagnosis, because to date, no study has obtained all data required for age estimates from one single reference population. The verification of age estimates carried out at the Institute of Legal Medicine in Berlin (Charité) allowed indirect conclusions about the range of combined overall age diagnoses. To verify our estimates, we inspected the court case files of persons examined for age estimation purposes to see whether the actual age of these persons was established during the court proceedings. We found that in 41 cases where the age of the person concerned could be determined beyond doubt, deviation between the estimated and actual age lay within a range of ±12 months [15].

In a questionnaire survey on forensic age estimation practice in the German-speaking area, Geserick and Schmeling [4] found that the main countries and regions of origin of the persons under examination were Africa, Turkey, Rumania, the Balkans, Lebanon, and Vietnam. Since reference studies that can be used for forensic purposes are generally not available for these areas of origin, a question of major practical relevance to estimating age arises, namely, whether there are significant differences in the rate of ossification between various ethnic groups which would contraindicate the application of relevant age standards to members of ethnic groups other than the reference population.

In a comprehensive study of relevant literature on the time frame for ossification of the hand bones, which is considered representative for the whole skeletal system, Schmeling et al. [13] showed that ethnic origin apparently exerts no noteworthy influence on ossification rates. In contrast, the level of economic progress and modernization in medicine in a given population seems to be a key factor affecting the rate of ossification, in that a high modernization level accelerates ossification rates, whereas a low level delays ossification. When performing age estimations, the expert opinion should therefore pay attention to the issue of different modernization levels [17].

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References

1. Andersen E (1971) Comparison of Tanner–Whitehouse and Greulich–Pyle methods in a large scale Danish survey. Am J Phys Anthropol 35:373–376
2. Cole AJL, Webb L, Cole TJ (1988) Bone age estimation: a comparison of methods. Br J Radiol 61:683–686
3. Dünkel F, van Kalmthout A, Schüler-Springorum H (1997) Entwicklungstendenzen und Reformstrategien im Jugendstrafrecht im europäischen Vergleich. Forum, Mönchengladbach
4. Geserick G, Schmeling A (2001) Übersicht zum gegenwärtigen Stand der Altersschätzung Lebender im deutschsprachigen Raum. In: Oehmichen M, Geserick G (eds) Osteologische Identifikation und Altersschätzung. Schmidt-Römhild, Lübeck, pp 255–261
5. Greulich WW, Pyle SI (1959) Radiographic atlas of skeletal development of the hand and wrist. Stanford University Press, Stanford, CA
6. Johnston FE, Zimmer LO (1989) Assessment of growth and age in the immature skeleton. In: Iscan MY, Kennedy KAR (eds) Reconstruction of life from the skeleton. Liss, New York, pp 11–21
7. Kaatsch H-J (2001) Juristische Aspekte der Altersschätzung. In: Oehmichen M, Geserick G (eds) Osteologische Identifikation und Altersschätzung. Schmidt-Römhild, Lübeck, pp 243–254
8. King DG, Steventon DM, O'Sullivan MP, Cook AM, Hornsby VP, Jefferson IG (1994) Reproducibility of bone ages when performed by radiology registrars: an audit of Tanner and Whitehouse II vs. Greulich and Pyle methods. Br J Radiol 67:848–851
9. Olze A, Schmeling A, Taniguchi M, Maeda H, Van Niekerk P, Wernecke K-D, Geserick G (2004) Forensic age estimation in living subjects: the ethnic factor in wisdom tooth mineralization. Int J Legal Med 118:170–173
10. Olze A, Bilang D, Schmidt S, Wernecke K-D, Geserick G, Schmeling A (2005) Validation of common classification systems for assessing the mineralization of third molars. Int J Legal Med 119:22–26
11. Paewinsky E, Pfeiffer H, Brinkmann B (2005) Quantification of secondary dentine formation from orthopantomograms—a contribution to forensic age estimation methods in adults. Int J Legal Med 119:27–30
12. Roche AF, Chumlea WC, Thissen D (1988) Assessing the skeletal maturity of the hand–wrist: Fels method. Thomas, Springfield, IL
13. Schmeling A, Reisinger W, Loreck D, Vendura K, Markus W, Geserick G (2000) Effects of ethnicity on skeletal maturation—consequences for forensic age estimations. Int J Legal Med 113:253–258
14. Schmeling A, Kaatsch H-J, Marré B et al (2001) Empfehlungen für die Altersdiagnostik bei Lebenden im Strafverfahren. Rechtsmedizin 11:1–3
15. Schmeling A, Olze A, Reisinger W, König M, Geserick G (2003) Statistical analysis and verification of forensic age estimation of living persons in the Institute of Legal Medicine of the University Hospital Charité. Leg Med 5:S367–S371
16. Schmeling A, Schulz R, Reisinger W, Mühler M, Wernecke K-D, Geserick G (2004) Studies on the time frame for ossification of medial clavicular epiphyseal cartilage in conventional radiography. Int J Legal Med 118:5–8

17. Schmeling A, Schulz R, Danner B, Rösing FW (2005) The impact of economic progress and modernization in medicine on the ossification of hand and wrist. Int J Legal Med DOI: 10.1007/s00414-005-0007-4
18. Schulz R, Mühler M, Mutze S, Schmidt S, Reisinger W, Schmeling A (2005) Studies on the time frame for ossification of the medial epiphysis of the clavicle revealed by CT scans. Int J Legal Med 119:142–145
19. Tanner JM, Whitehouse RH, Marshall WA, Healy MJR, Goldstein H (1975) Assessment of skeletal maturity and prediction of adult height (TW2 method). Academic, London
20. Tanner JM, Healy MJR, Goldstein H, Cameron N (2001) Assessment of skeletal maturity and prediction of adult height (TW3 method). Saunders, London
21. Thiemann H-H, Nitz I (1991) Röntgenatlas der normalen hand im Kindesalter. Thieme, Leipzig