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SHORT COMMUNICATION

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The impact of economic progress and modernization in medicine on the ossification of hand and wrist

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Abstract One of the main criteria used for age estimations of young living subjects is the developmental status of the ossification of hand bones. The impact of economic progress and modernization in medicine on ossification rates in a given population still requires further clarification. We selected 36 samples from literature for which the ossification status had been determined with the Greulich–Pyle method and analyzed specific economic data (per capita income) and demographic data (life expectancy at birth) as parameters of modernization. To describe the influence of these parameters on the rate of ossification, we performed a regression analysis and found that a relatively high level of economic progress and modernization in medicine coincides with high ossification rates, while relatively low modernization seems to delay ossification. When performing age estimations, the expert opinion should therefore pay attention to the issue of different modernization levels.

Keywords Forensic age diagnosis · Skeletal age · Modernization

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Introduction

Age estimations of living subjects for forensic purposes, i.e., to assess their criminal liability and decide whether adult criminal law applies, is one of the more recent research areas of forensic science [23–25, 33, 34]. In many countries, the age thresholds of relevance to criminal prosecution lie between 14 and 21 years [5]. In line with recommendations for determining the age of living subjects for the purposes of criminal prosecution drawn up by the Study Group on Forensic Age Diagnostics (http://www.charite.de/rechtsmedizin/agfad/index.htm), a forensic age estimation should consist of a physical examination, an X-ray of the left hand, and a dental examination which records dentition status and evaluates an orthopantomogram. In addition, a radiological or CT examination of the medial clavicular epiphysis is recommended to establish whether a person has attained 21 years of age [32].

One of the main criteria used in radiological age diagnostics is the developmental status of the ossification of hand bones. An as-yet-insufficiently-answered question of major significance to age estimation practice is how economic progress and modernization in medicine influence the rate of ossification in a given population. For the purpose of this article, modernization means the changes that have restructured societies throughout the world over the last two centuries. These changes include progress in the medical field, the spread of sanitary knowledge, the evolution of industry, and the associated economic growth [37]. Modernization began in Europe and has been completed in most European countries today, while many developing countries have not yet experienced this stage.

This paper aims at quantifying the impact of modernization on ossification rates, using regression analysis.

Material and method

The radiographic atlas method developed by Greulich and Pyle [9] is the most commonly used method for determining the skeletal age of living non-adults. We culled 27 studies and found usable data for 36 samples which provide insights into the ossification rates of the populations examined by reference to the Greulich–Pyle method [1–4, 6, 8, 10–19, 21, 22, 26–30, 35, 36, 41, 42]. For the 36 samples, and separately for both sexes, we recorded the year of publication, the time of examination, the number of cases, and the age group examined. We found that the samples included different age groups, with four samples only covering the age group of 0–9 years and the other four covering the age group of 10–18 years. For each age within a group, and separately for both sexes, we determined the deviation of skeletal age from that of the Greulich–Pyle population. The mean deviation of the skeletal age of one sample is expressed as the arithmetic mean of these values. In addition, for each sample (i.e., for the country and year of the study) we recorded per capita income as an economic parameter and life expectancy at birth as a demographic parameter ([20]; OECD 2001, CD Health Data, Paris; [38–40]). Data were interpolated for a small number of cases where no information was available on the year of examination.

For describing the relationship between the variables, regression analysis is the method of choice. For the three variables, income, life expectancy, and ossification, multiple regression seemed to suit the purpose best; in this case, however, variability was very high, and it was almost impossible to fit a line through the relatively small cloud of points, so only simple regressions were computed.

The size of the 36 samples differed very widely. Therefore, the square root of the number of cases was used for weighting.

Results

Figures 1, 2, 3, and 4 show separately for the two sexes the regression lines with confidence intervals, the regression equations, and the correlation coefficients describing the influence of per capita income and life expectancy at birth on the rate of ossification.

The correlation coefficients are relatively low and lie between 0.16 (life expectancy at birth and ossification rate in females) and 0.43 (per capita income and ossification rate in females). The deviation of individual points for the observed pairs was accordingly high.

A 95% confidence interval for the regression line means that there is a 95% probability that other regression lines for additional data will lie within that interval. A 68 (95)% confidence interval means that 68 (95)% of the values actually observed lie within that interval.

Discussion

A questionnaire survey on the current state of forensic age diagnostics in the German-speaking area found that the main countries and regions of origin of the persons under

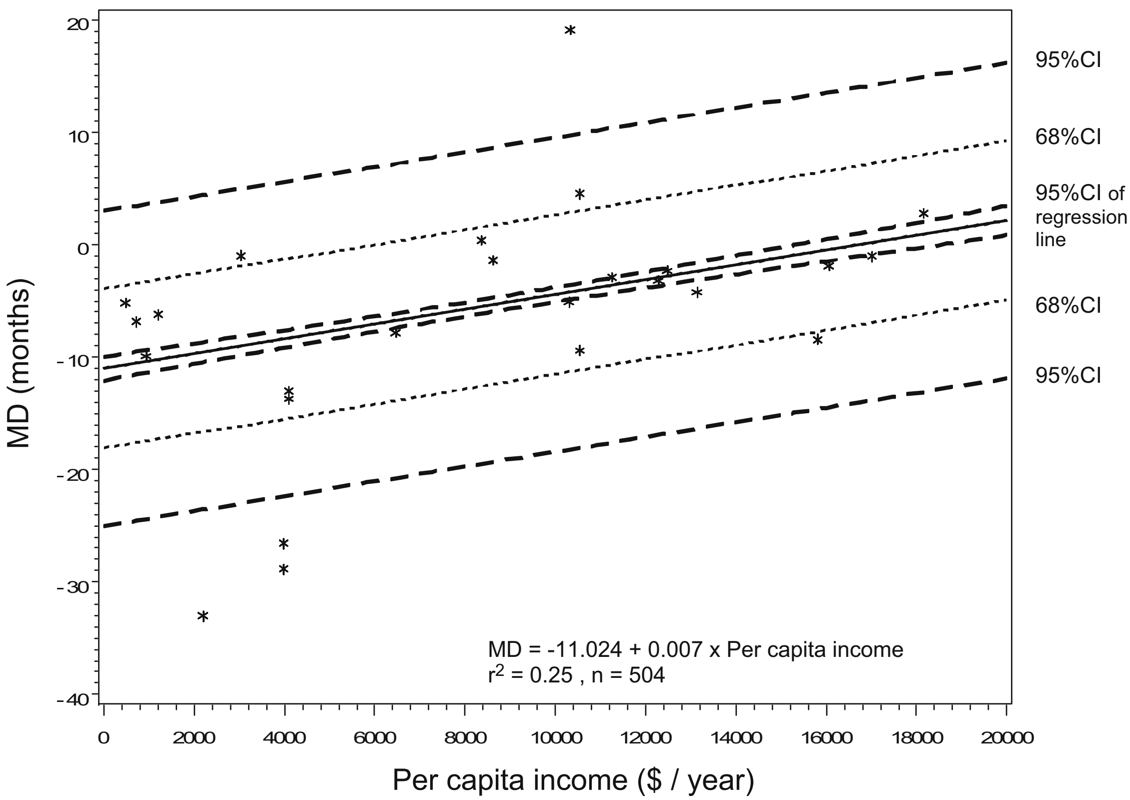

Fig. 1 Regression for the influence of per capita income on ossification rates in males. *MD* indicates mean deviation of the skeletal age of the sample from that of the Greulich–Pyle; r^2, correlation coefficient; *n*, number of cases; *CI*, confidence interval

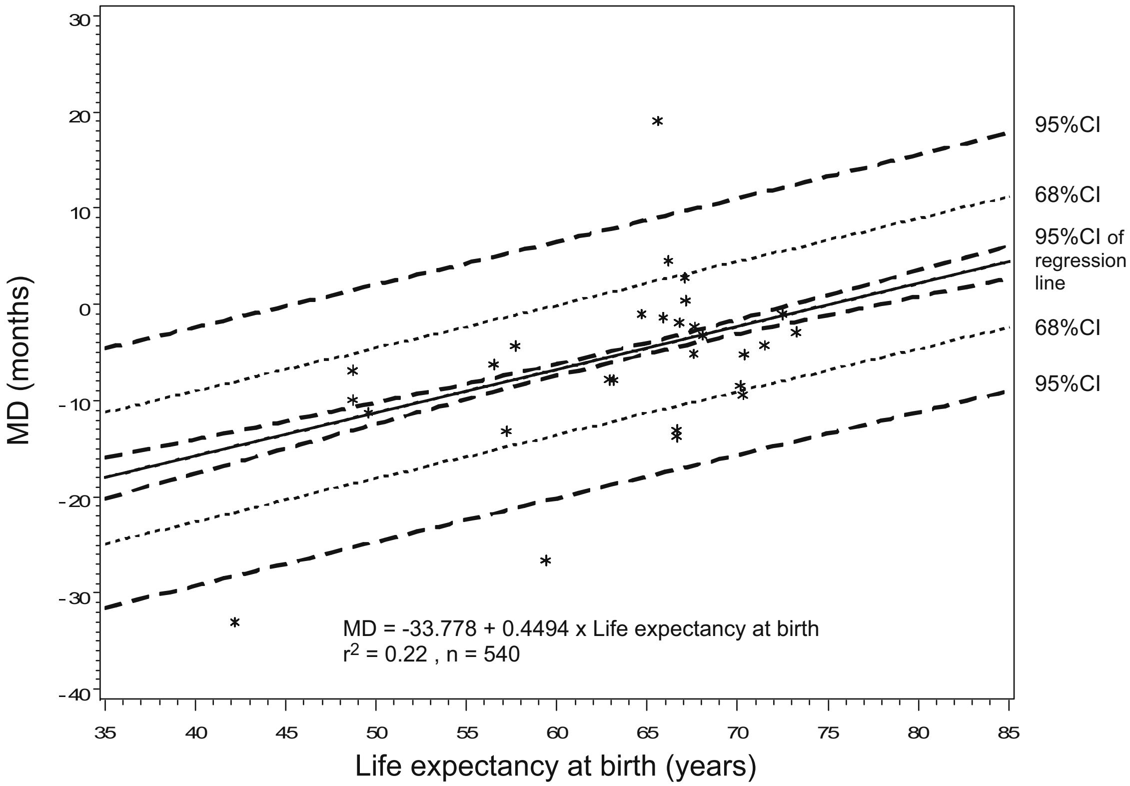

Fig. 2 Regression for the influence of life expectancy at birth on ossification rates in males

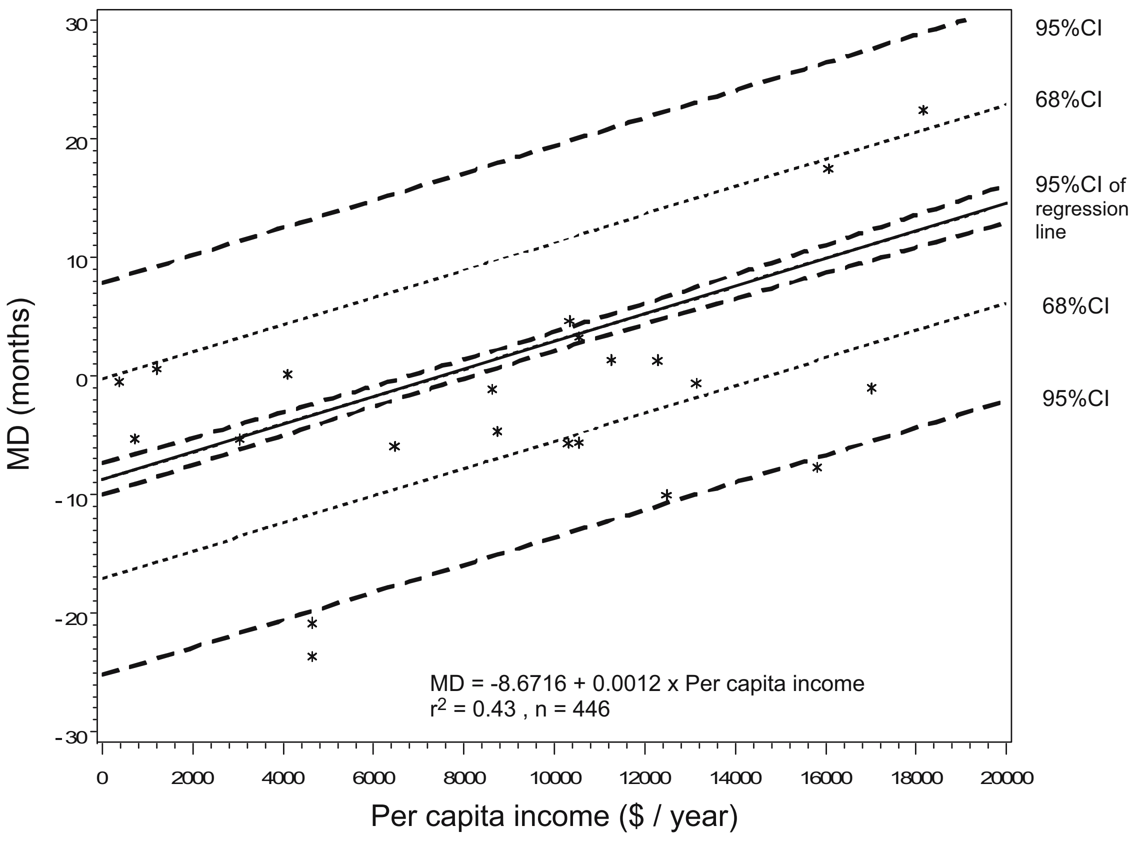

Fig. 3 Regression for the influence of per capita income on ossification rates in females

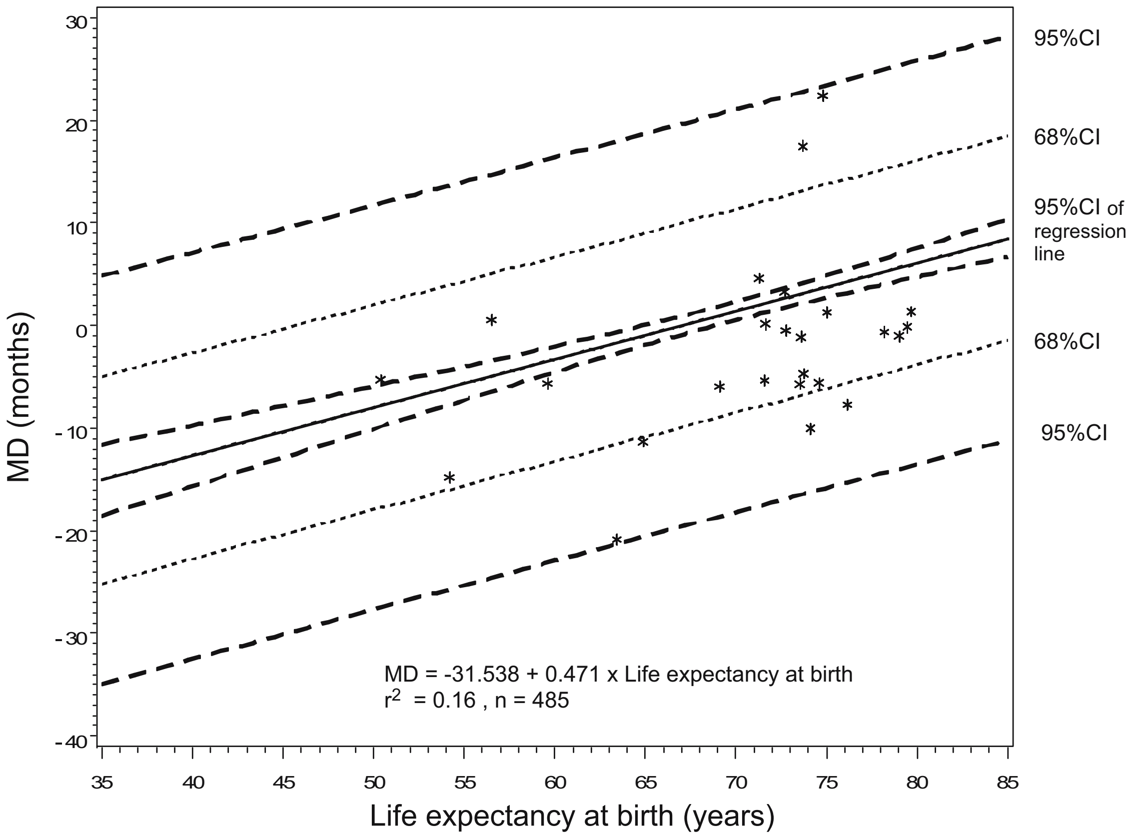

Fig. 4 Regression for the influence of life expectancy at birth on ossification rates in females

examination are Africa (29%), Turkey (27%), Rumania (26%), the Balkans (7%), Lebanon (4%), and Vietnam (3%) [7]. Studies on skeletal maturation that might aid forensic investigations are not usually available for these regions. This raises a question of major practical relevance when estimating age, namely, whether the reference data customarily used for forensic diagnosis, derived from white North Americans on the one hand and central and northern Europeans on the other, can also be applied to members of other ethnic groups.

In a comprehensive study of relevant literature, we were able to demonstrate that the geneto-geographic origin of a person does not appear to affect skeletal maturity [31].

The present study is the first to investigate the impact of medical and economic progress on the rate of ossification.

The regression lines (Figs. 1, 2, 3, and 4) are notably below the zero point on the axis of ordinates. This means that the ossification rate of almost all samples examined is retarded compared to that of the Greulich–Pyle population. The reason for this is the extremely high socioeconomic status of the subjects examined by Greulich and Pyle.

The computed correlation coefficients are relatively small, and the deviations of observed points from the regression line are accordingly high. This can be explained if one looks at the factors affecting the variability of the growth rate. The dominant factor is heritability, i.e., genetic control. The second most important factor is the systematic difference between the sexes. Other major factors are as-yet-immeasurable influences and chance. There is then a group of "minor" factors, such as physical constitution, illnesses, and modernization, which are less significant by comparison. Overall, variability between individuals is greater than between populations.

The heterogeneous age structure of the samples examined should be discussed as another reason for the relatively high confidence intervals of regressions. Moreover, it may be assumed that the samples included in the examination do not in every case represent the population of the respective country as a whole. Neither can it be ruled out that in less developed countries with limited statistical data collection, publicly available data on per capita income and life expectancy at birth are not reliable.

The following example is meant to illustrate the forensic relevance of the regressions determined. If we assume a life expectancy at birth of 40 years in a given African country (e.g., Burkina Faso in the mid-1980s) for the year the subject was born, the mean skeletal age of the population of that country would be 15 months below the Greulich–Pyle standard. Therefore, the skeletal age diagnosed in an investigation involving an adolescent offender would have to be increased by this amount. As a consequence, the suspect will be estimated as older, and there is less chance of falling below the age thresholds relevant for criminal prosecution. However, the accuracy of the corrective values is mitigated by the relatively high variation. In the example given above, the 68% confidence interval would be ±7 months, and the 95% interval, ±14 months.

Conclusions

A high level of medical and economic development accelerates ossification rates, whereas a low modernization level delays ossification. If radiological age diagnostics use the Greulich–Pyle standards for persons originating from a country with a comparatively low modernization status, the age of that person will be underestimated. When performing age estimations, the expert opinion should therefore draw attention to the issue of different modernization levels.

References

1. Andersen E (1968) Skeletal maturation of Danish school children in relation to height, sexual development, and social conditions. Acta Paediatr Scand, Suppl 185:1–133
2. Blanksby BA, Brogan WF, McKnight HP, Sprague PL (1975) A skeletal age survey of primary school children in western Australia. Aust Paediat J 11:169–171
3. Brown T, Grave KC (1976) Skeletal maturation in Australian Aborigines. Aust Pediat J 12:24–80
4. Chan ST, Chang KSF, Hsu FK (1961) Growth and skeletal maturation of Chinese children in Hongkong. Am J Phys Anthropol 19:289–300
5. Dünkel F, van Kalmthout A, Schüler-Springorum H (1997) Entwicklungstendenzen und Reformstrategien im Jugendstrafrecht im europäischen Vergleich. Forum, Mönchengladbach
6. Fry EI (1960) Health survey of children from Raratonga, Cook Islands. III. Skeletal age and skeletal observations. J Trop Pediatr 6:75–79
7. 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
8. Greulich WW (1951) The growth and developmental status of Guamanian school children in 1947. Am J Phys Anthropol 9:55–70
9. Greulich WW, Pyle SI (1959) Radiographic atlas of skeletal development of the hand and wrist. Stanford University Press, Stanford
10. Groell R, Lindbichler F, Riepl T, Gherra L, Roposch A, Fotter R (1999) The reliability of bone age determination in central European children using the Greulich and Pyle method. Br J Radiol 72:461–464
11. Haavikko K, Kilpinen E (1973) Skeletal development of Finnish children in the light of hand–wrist roentgenograms. Proc Finn Dent Soc 69:182–190
12. Jimenez-Castellanos J, Carmona A, Catalina-Herrera CJ, Vinuales M (1996) Skeletal maturation of wrist and hand ossification centers in normal Spanish boys and girls: a study using the Greulich–Pyle method. Acta Anat 155:206–211
13. Johnston FE (1963) Skeletal age and its prediction in Philadelphia children. Hum Biol 35:192–202
14. Johnston FE (1971) The use of the Greulich–Pyle method in a longitudinal growth study. Am J Phys Anthropol 35:353–357
15. Kapalin V, Picko V (1964) The skeletal age of school children and its dependences. Ceskoslov Hyg 9:342–356
16. Koski K, Haataja J, Lappalainen M (1961) Skeletal development of hand and wrist in Finnish children. Am J Phys Anthropol 19:379–382
17. Levine E (1972) The skeletal development of children of four South African populations. Hum Biol 44:399–412
18. Low WD (1975) Assessing skeletal maturity by inspection and bone-specific methods with the atlas of Greulich and Pyle. Z Morphol Anthropol 67:1–5
19. Low WD, Chan ST, Chang KSF, Lee MMC (1964) Skeletal maturation of southern Chinese children. Child Dev 35:1313–1336
20. Maddison A (2001) The world economy: a millennial perspective. Development Centre OECD, New York
21. Mathiasen MS (1973) Determination of bone age and recording of minor skeletal hand anomalies in normal children. Dan Med Bull 20:80–85
22. Newman MT, Collazos C (1957) Growth and skeletal maturation in malnourished Indian boys from the Peruvian Sierra. Am J Phys Anthropol 15:431
23. 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 Leg Med 118:170–173
24. 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 Leg Med 119:22–26
25. 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 Leg Med 119:27–30
26. Prader A, Budliger H (1977) Körpermasse, Wachstumsgeschwindigkeit und Knochenalter gesunder Kinder in den ersten zwölf Jahren (Longitudinale Wachstumsstudie Zürich). Helv Paediatr Acta, Suppl 37:5–44
27. Rikhasor RM, Qureshi AM, Rathi SL, Channa NA (1999) Skeletal maturity in Pakistani children. J Anat 195:305–308
28. Roche AF (1967) A study of skeletal maturation in a group of Melbourne children. Aust Paediat J 3:123–127
29. Roche AF, Roberts J, Hamill PVV (1975) Skeletal maturity of children 6–11 years: racial, geographic area and socioeconomic differentials, United States. National Center for Health statistics, series 11, no. 149. DHEW Publication no. (HRA) 76–1631, Rockville, Maryland
30. Roche AF, Roberts J, Hamill PVV (1978) Skeletal maturity of youth 12–17 years. Racial, geographic area and socioeconomic differentials (vital and health statistics. US Dept. of Health, Education and Welfare. Series 11. No. 167). US Government Printing Office, Washington, D.C.
31. Schmeling A, Reisinger W, Loreck D, Markus W, Geserick G (2000) Effects of ethnicity on skeletal maturation: consequences for forensic age estimations. Int J Leg Med 113:253–258
32. Schmeling A, Kaatsch H-J, Marré B, Reisinger W, Riepert T, Ritz-Timme S, Rösing FW, Rötzscher K, Geserick G (2001) Empfehlungen für die Altersdiagnostik bei Lebenden im Strafverfahren. Rechtsmedizin 11:1–3
33. 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 Leg Med 118:5–8
34. 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. DOI: 10.1007/s00414-005-0529-9
35. Stuart HC, Reed RB (1959) Longitudinal studies of child health and development. Series II. Reports based on completed case studies. Pediatrics (Suppl) 24:875–885
36. Stubbe P, Hölscher A, Weigel W (1974) Über die Vorausberechnung der Endlänge von Kindern. Monschr Kinderheilkd 122:887–890
37. Ulijaszek SJ (1998) Modernization and growth. In: Ulijaszek SJ, Johnston FE, Preece MA (eds) The Cambridge encyclopedia of human growth and development. Cambridge University Press, Cambridge, pp 402–403

38. United Nations (1955) Age and sex patterns of mortality. Model life-tables for under-developed countries. UN, New York
39. United Nations (1979) Demographic yearbook: special issue–natality. UN, New York
40. United Nations (1993) Demographic yearbook: special issue—population ageing and the situation of elderly persons. UN, New York
41. Vignolo M, Milani S, DiBattista E, Naselli A, Mostert M, Aicardi G (1990) Modified Greulich–Pyle, Tanner–Whitehouse, and Roche–Wainer–Thissen (knee) methods for skeletal age assessment in a group of Italian children and adolescents. Eur J Pediatr 149:314–317
42. Wenzel A, Droschl H, Melsen B (1984) Skeletal maturity in Austrian children assessed by the GP and the TW-2 methods. Ann Hum Biol 11:173–177