Eur J Pediatr (1990) 149:314–317

European Journal of
Pediatrics

Modified Greulich-Pyle, Tanner-Whitehouse, and Roche-Wainer-Thissen (knee) methods for skeletal age assessment in a group of Italian children and adolescents

M. Vignolo[1], S. Milani[2], E. DiBattista[1], A. Naselli[1], M. Mostert[3], and G. Aicardi[1]

[1]Department of Child Welfare and Neonatal Medicine, University of Genoa, Institute G. Gaslini, Genoa, Italy
[2]Institute of Biometry and Medical Statistics, University of Milan, Milan, Italy
[3]Paediatric Clinic, University of Turin, Turin, Italy

Abstract. Modified Greulich-Pyle (GP), Tanner et al. 2, radius, ulna and short bones (TW2-RUS), TW2-20-bone and Roche-Wainer-Thissen RWT (knee) skeletal age assessments were made in an Italian population sample of 128 males and 93 females aged 4.1–16.9 years. All the scales appear to be well-suited to the Italian population despite minor differences. A very high correlation was found between the assessment of knee skeletal ages by the RWT method and that of the hand-wrist by the GP and TW2 systems in the same subject without sex and age-associated variations.

Key words: Bone development – Skeletal age methods – Italian population

Introduction

Skeletal age is the most commonly used measure of biological age. Since populations exhibit appreciable variations in the rate of bone development [1, 5, 7, 9, 15, 17, 20, 21, 23, 24], caution must be excercised in interpreting the results of various skeletal age assessment methods in populations which deviate from the source samples of the methods.

To test the accuracy of the Greulich-Pyle (GP) [8] and Tanner-Whitehouse (TW2) [19] techniques for the hand-wrist and of Roche-Wainer-Thissen (RWT) for the knee [16], when applied to Italian children and adolescents, the relationship between chronological and skeletal age determined by means of these methods was evaluated in a group of healthy subjects.

As knee standards have hardly been used and the correlation between knee and hand-wrist skeletal development in the same subject has not been clearly defined, correlation coefficients of RWT versus GP and TW2 skeletal ages were also calculated.

Offprint requests to: M. Vignolo, Cattedra di Auxologia, Istituto G. Gaslini, via 5 Maggio, 39, I-16147 Genova Quarto, Italy

Abbreviations: GP = Greulich and Pyle; TW2 = Tanner et al. 2; RUS = radius, ulna and short bones; RWT = Roche-Wainer-Thissen

Subjects and methods

As a reference group of the Italian population, the records of 128 boys and 93 girls aged 4.1–16.9 years referred to the Auxology Service of the "Istituto G. Gaslini" in Genoa between 1981 and 1986 for adult height prediction, were reviewed. Subjects were eligible if their height was between the 10th and 90th percentile according to the growth charts of Tanner and Whitehouse [18].

Skeletal maturation was determined in view of GP, TW2 and RWT method requirements. The GP method was slightly modified [4]: radius-ulna, metacarpals and phalanges, carpals were assessed separately and a weighted linear combination of these area-specific ratings was adopted (using a coefficent of 0.4 for radius and ulna, 0.4 for metacarpals and phalanges and 0.2 for the carpal bones).

Two independent assessors rated each radiograph without knowledge of the identity of the subjects. Both observers had received a specific training and assessed the sets of test radiographs provided by the authors of the TW2 and RWT systems with high comparability and reproducibility (reliability between and within observers is given in Table 1).

The TW2 carpal system was excluded from the present study as carpal bones reach maturity at 13 years in girls and of 15 years in boys and are markedly variable in the rates and pattern of maturation.

For GP, Tanner and Whitehouse 2-radius, ulna and short bones (TW2-RUS), TW2-20-bone and RWT methods, the mean value of two separate assessments was taken. When the difference between the estimates was more than 0.5 year

Table 1. Standard errors of measurement both between and within observers (years)

	Between observers	Within observer	
		1st	2nd
GP	0.14	0.12	0.11
TW2-RUS	0.21	0.15	0.19
TW2-20-bone	0.10	0.09	0.13
RWT	0.08	0.07	0.06

Table 2. Age distribution, means and SD of chronological age and of the modified GP, TW2-RUS, TW2-20-bone and RWT skeletal ages in both sexes for two year groupings

Age class	n		Chronological age (years)		Skeletal ages (years)							
					Modified GP		TW2-RUS		TW2-20 bone		RWT	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
4–5	15	10	4.9 (0.58)	4.8 (0.69)	4.5 (0.54)	4.5 (0.67)	4.8 (0.60)	4.6 (0.93)	4.5 (0.62)	4.6 (0.76)	4.8 (0.82)	4.8 (0.81)
6–7	8	14	6.8 (0.58)	7.1 (0.55)	6.6 (0.59)	7.0 (0.70)	7.0 (0.48)	7.6 (0.87)	6.7 (0.90)	7.1 (0.82)	7.0 (0.73)	7.3 (1.02)
8–9	10	18	9.0 (0.62)	9.3 (0.53)	8.6 (0.68)	9.2 (0.65)	8.8 (0.71)	9.5 (0.69)	8.8 (0.67)	9.1 (0.61)	9.0 (0.95)	9.6 (8.73)
10–11	31	23	11.0 (0.59)	11.0 (0.48)	10.7 (0.93)	11.0 (0.57)	10.9 (1.17)	11.5 (0.80)	10.8 (0.91)	11.0 (0.64)	11.2 (0.99)	11.5 (0.77)
12–13	41	22	12.6 (0.83)	12.9 (0.54)	12.7 (0.67)	12.8 (0.79)	13.6 (0.90)	13.5 (0.78)	13.3 (0.94)	12.6 (1.00)	13.3 (0.83)	13.1 (0.89)
>14	23	6	15.3 (0.85)	14.4 (0.26)	14.8 (0.89)	14.4 (0.47)	14.5 (0.86)	14.9 (0.59)	15.3 (0.75)	14.4 (0.54)	15.1 (0.91)	14.9 (0.63)

(95% confidence limit for the GP and TW2-RUS intra- and interobserver reliability [7]) repeat determinations were made. The mean of the second assessment was accepted, even when the difference remained at 0.5 years. This occurred in 13 cases for GP, 9 for TW2-RUS, 15 for TW2-20-bone and 7 for RWT.

Calculations needed for TW2 and RWT skeletal age assessments were obtained by using the growth evaluation computerized system program [2].

Results

Table 2 shows the age distribution of subjects, the means and standard deviation (SD) for chronological age for GP, TW2-RUS, TW2-20-bones and RWT skeletal ages in boys and girls separately for 2 year groupings.

The relationship of GP, TW2-RUS, TW2-bone and RWT skeletal ages to chronological age was evaluated by multiple regression analysis. Second degree polynomials were fitted to the data (with 2 intercepts, 2 first degree and 2 second degree terms, one of each sex). Unnecessary terms were then removed from the models. Results are shown in Figs. 1–4.

Modified GP method

The regression coefficient is around 1 (1.00746 ± 0.01103 – $t = 0.68$, $P = 0.50$ under the hypothesis $\beta = 1$). The difference between sexes is significant ($P = 0.002$). This method systematically underestimates chronological age by 0.4 years in boys (SE = 0.13, $P = 0.002$) and by 0.2 years in girls (SE = 0.12, $P = 0.13$).

TW2 method

As with the RUS system, the regression coefficient (1.06043 ± 0.01627) is significantly >1 ($P = 0.0002$). The systematic inac-

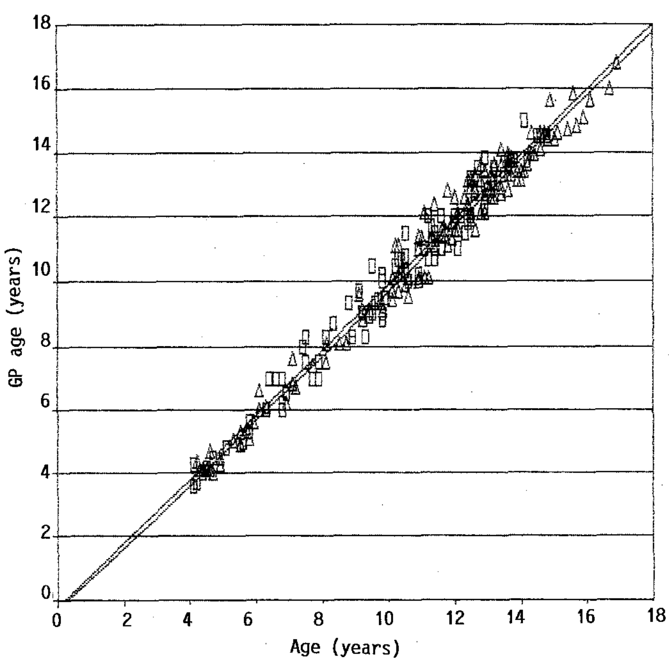

Fig. 1. Regression of the modified GP skeletal age on chronological age, for boys (△) and girls (□)

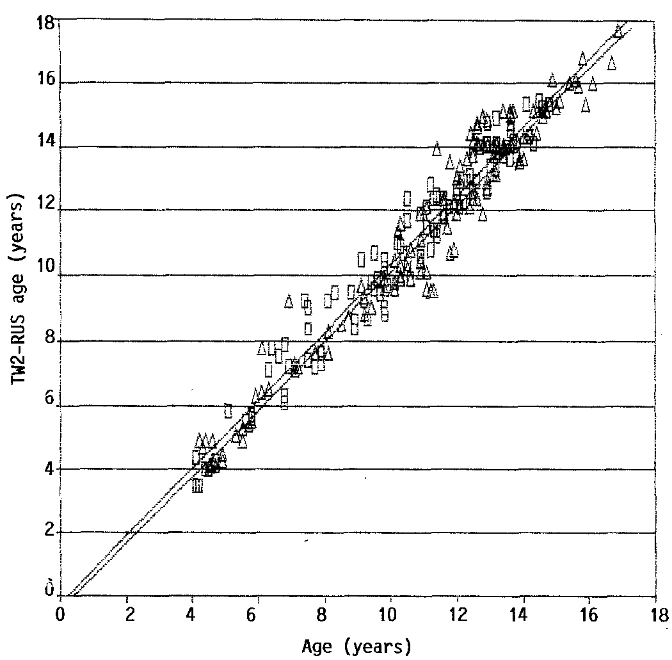

Fig. 2. Regression of TW2-RUS skeletal age on chronological age. Symbols as for Fig. 1

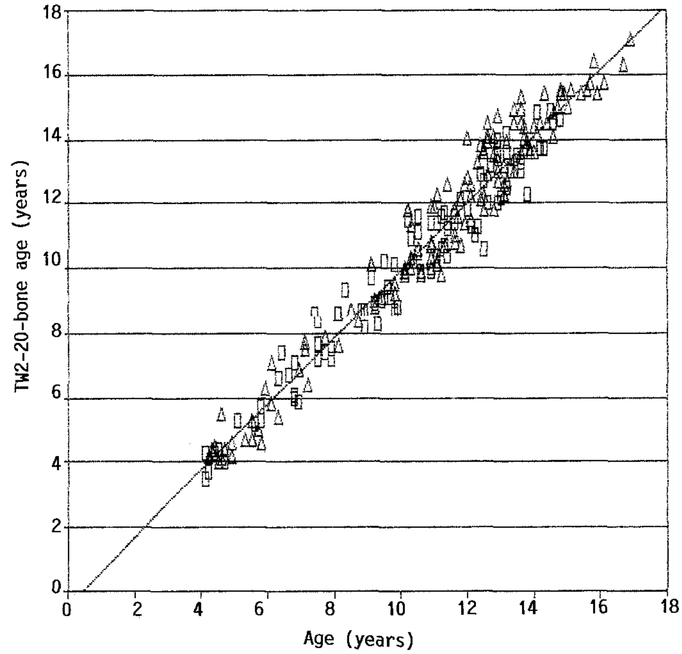

Fig. 3. Regression of TW2-20-bone skeletal age on chronological age for both sexes. Symbols as for Fig. 1

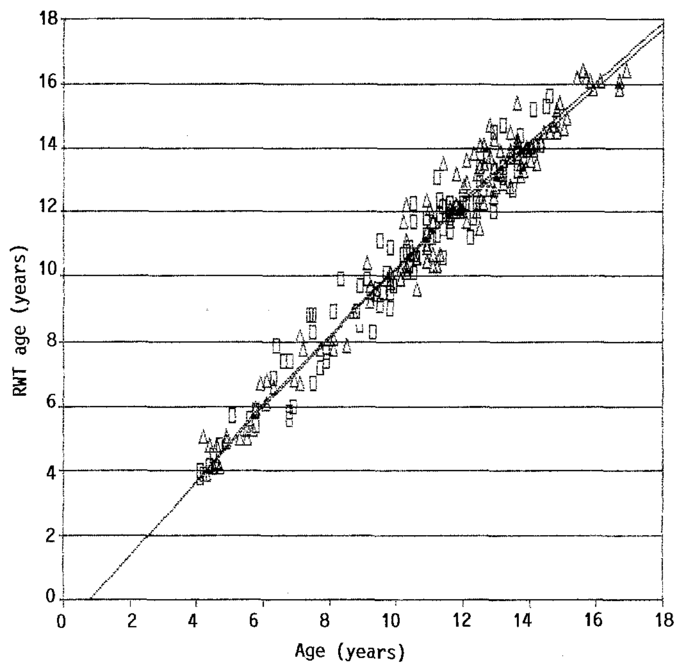

Fig. 4. Regression of RWT skeletal age on chronological age. Symbols as for Fig. 1

curacy is significantly higher in males ($P = 0.014$). At younger ages the system underestimates by about 0.3 years in boys and by about 0.05 years in girls. It overestimates by 0.2–0.3 years in girls aged 4–9 years, while later an overestimation of about 0.5 is observed at 12–15 years in both sexes.

The 20-bone system is not significantly different in boys and girls, the linear regression coefficient (1.03104 ± 0.01524) is significantly above 1 ($P = 0.04$). The method underestimates by about 0.4 (+ 0.17) years with respect to chronological age at younger ages. This difference becomes smaller up to 12.5 years where 20-bone age coincides with chronological age. At older ages there is a slight overestimation (about 0.1 years).

Table 3. Correlation coefficients between ratings of hand-wrist skeletal age by the modified GP, TW2-RUS, TW2-20-bone methods and knee ratings by RWT method calculated within chronological age classes for boys and girls separately

Age class	GP vs RWT		TW2-RUS vs RWT		TW2-20-bone vs RWT	
	Boys	Girls	Boys	Girls	Boys	Girls
<8	0.955	0.962	0.972	0.951	0.975	0.913
8–13	0.950	0.950	0.953	0.949	0.916	0.937
>13	0.872	0.886	0.867	0.888	0.808	0.851

RWT method

The relationship between RWT bone age and chronological age requires the introduction of a second degree term (0.012564 + 0.004473). This quadratic coefficient is the same in boys and girls. At younger ages the RWT bone age underestimates chronological age by 0.3 years. Between 5 and 6 years, the two values coincide and later tend towards a slight overestimation that at 10–11 years reaches 0.4 years. At 15 years RWT bone age is again about the same as chronological age and at 16 years a slight underestimation is observed.

The correlation coefficients between GP, TW2-RUS, TW2-20-bone and RWT skeletal ages, calculated within three different chronological age classes for boys and girls separately showed no age and sex-associated variations (Table 3).

Discussion

Assessments of skeletal age using the modified GP, TW2 and RWT methods are not perfectly equivalent, possibly because these systems are related to different skeletal areas and different source populations.

GP skeletal ages display a slight systematic lag to chronological age in boys but match chronological age more closely in girls. The slight discrepancy between sexes, as seen in other studies [6, 11, 19], probably reflects the choice of plates in the GP standards, rather than a real difference [19].

GP bone development standard was slightly advanced with respect to European children, being 0.75 years ahead at age 6 and upwards for British subjects in the 1950s, assessed using TW2 standards [19], and being about 0.8 years ahead in boys and 0.5 years in girls for Swiss, Finnish and Danish populations in the 1960s–1970s [11, 19, 21]. A more recent study on Austrian children suggests, as does this present case series, that European populations may now be approaching GP standards [22].

In agreement with the results of previous studies carried out in Italy [12, 14], the TW2-RUS system matches chronological age until puberty when a catch up in RUS age is observed. This advancement of 5–6 months around 12–15 years in boys and around 11–14 years in girls probably reflects the earlier growth spurt of Italian as compared to British subjects [3, 13]. A similar pattern of RUS bone development across ages is also seen in other European populations [21, 22], and in French-Canadian [6] and Japanese children [10].

The TW2-20-bone skeletal ages closely follow chronological age in subjects of both sexes. A tendency is observed towards a lag behind the British standard at earlier ages with an increase in maturation after 11–12 years.

The RWT skeletal ages in the group of subjects examined presents a slight retardation at both ends of the age scale and a slight advancement between 7 and 14 years in both sexes. At present this method is not currently used and data are not available in with regard to the reliability of this system in European populations. A very high correlation is observed between the knee and hand-wrist skeletal age ratings in the same subject, contrary to the findings of Roche et al. [16]. It is important to note that in the present study the values considered in calculating correlations are the mean of the ratings of two observers and that the age banding used is coarse, due to the fairly small number of subjects.

In conclusion, the modified GP, TW2 and RWT methods are well-suited for the evaluation of skeletal maturity in Italian children and adolescents with only minor differences between the Italian population and the reference standards of the methods. Adjustments to produce an exact correspondence of these scales with chronological ages would appear unnecessary for most clinical or research purposes.

Acknowledgement. This work was supported by a grant from the G. Gaslini Institute, Genova.

References

1. Acheson RM, Vicencio JH, Fowler GB (1966) Studies in the reliability of assessing skeletal maturity from X-rays. III. Greulich and Pyle and Tanner-Whitehouse methods contrasted. Hum Biol 38:204–218
2. Aicardi G, Albino E, Vignolo M, DiBattista E, Naselli A (1983) Auxologia e informatica: proposta di un sistema computerizzato per la valutazione auxologica individuale. Minerva Pediatr 35: 617–632
3. Aicardi G, Toni E de, DiBattista E, Vignolo M, Naselli A (1985) Eventi morfo-biologici della puberta'. Riv It Pediatr 11:222–230
4. Aicardi G, DiBattista E, Naselli A, Vignolo M, DeScrilli A (1986) Affidabilità dei più comuni metodi di previsione della statura adulta in un campione di adolescenti italiani. Acta Med Auxol 18:55–65
5. Andersen E (1971) Comparison of Tanner-Whitehouse and Greulich-Pyle methods in a large scale Danish survey. Am J Phys Anthropol 35:373–376
6. Baughan B, Demirjian A, Levesque GY (1979) Skeletal maturity standards for French-Canadian children of school-age with a discussion of the reliability and validity of such measures. Hum Biol 51:353–370
7. Cameron N (1984) The measurement of human growth. Croom Helm, London
8. Greulich WW, Pyle SI (1959) Radiographic atlas of skeletal development of the hand and wrist, 2nd edn. Stanford University Press, Stanford
9. Johnson GF, Dorst JP, Kuhn JP, Roche AF, Davila GH (1973) Reliability of skeletal age assessments. Am J Roentg Rad Ther Nucl Med 118:320–327
10. Kimura K (1972) Skeletal maturation in Japanese according to the Oxford and Tanner-Whitehouse methods. Acta Anat Nippon 47: 358–372
11. Koski K, Haataja J, Lappalainen M (1961) Skeletal development of hand and wrist in Finnish children. Am J Phys Anthropol 19: 379–382
12. Nicoletti I, Cheli D, Cocco E, Puccetti L, Salvi A, Socci A (1976) Contributo allo studio della maturazione ossea nella popolazione italiana. Acta Med Auxol 8:5–48
13. Nicoletti I, Bruni V, Rolla M (1984) La diagnosi auxologica di 1^ e 2^ livello per la prevenzione e la clinica nelle alterazioni della crescita. Acta Med Auxol 16:3–31
14. Peris M, Manzi P, Martire M, Pastorin L, Rota A, Benso L (1983) La maturazione scheletrica a Torino in confronto agli standard britannici (maschi tra i 6 e gli 11 anni). Minerva Pediatr 35:959–960
15. Roche AF (1979) The measurement of skeletal maturation. In: Johnston FE, Roche AF, Susanne C (eds) Human physical growth and maturation. Plenum Press, New York, pp 61–82
16. Roche AF, Wainer H, Thissen D (1975) Skeletal maturity. The knee joint as a biological indicator. Plenum Press, New York
17. Tanner JM (1980) Principles in the evaluation of skeletal age. In: LaCauza C, Root AW (eds) Problems in pediatric endocrinology. Academic Press, London New York, pp 321–328
18. Tanner JM, Whitehouse RH (1976) Clinical longitudinal standard of height, weight, height velocity, weight velocity and the stages of puberty. Arch Dis Child 51:170–179
19. Tanner JM, Whitehouse RH, Marshall WA, Healy MJR, Goldstein H (1983) Assessment of skeletal maturity and prediction of adult height (TW2 method), 2nd edn. Academic Press, London
20. Taranger J (1980) Methodological aspects on the evaluation of skeletal maturity. In: LaCauza C, Root AW (eds) Problems in pediatric endocrinology. Academic Press, London New York, pp 335–340
21. Wenzel A, Melsen B (1982) Skeletal maturity in 6–16-year-old Danish children assessed by the Tanner-Whitehouse-2 method. Ann Hum Biol 9:277–281
22. Wenzel A, Droschl H, Melsen B (1984) Skeletal maturity in Austrian children assessed by the GP and the TW-2 methods. Ann Hum Biol 2:173–177
23. Zachmann M, Sobradillo B, Frank M, Frisch H, Prader A (1978) Bayley-Pinneau, Roche-Wainer-Thissen, and Tanner height predictions in normal children and in patients with various pathologic conditions. J Pediatr 93:749–755
24. Zachmann M, Frasier SD, McLaughlin J, Hurley L, Nessi P (1983) Importance and accuracy of bone age ratings in a computerized growth evaluation system. Horm Res 18:160–167

Received October 23, 1987 / Accepted August 10, 1989