

Assesment of Chronological Dental and Skeletal Age in Bulgarian Children in Mixed to Early Permanent Dentition

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ABSTRACT

Introduction: The assessment of chronological and skeletal age is particularly important for accurate diagnosis, prognosis and planning of orthodontic treatment.

Aim: To perform a comparative assessment of dental and skeletal age in children in mixed to early permanent dentition.

Materials and Methods: The study subjects included 52 children aged 7–12 years. Of these, 50.0% were boys and 50.0% were girls. Dental age was calculated from the mineralization of seven left mandibular permanent teeth determined using the Willems method on orthopantomography. Skeletal age was determined using a radiograph of the left hand and wrist, tracking the development of the phalanges according to the Björk, Grave and Brown method, using Schopf's (1978) sex-specific recalibration of the original criteria as the reference standard. Descriptive statistics, the paired- and independent-samples *t*-test, the Mann–Whitney *U* test and Spearman correlation were applied ($\alpha = 0.05$).

Results: Mean CA was 10.21 ± 1.37 years and mean Willems dental age was 10.64 ± 1.83 years; the Willems method overestimated CA by 0.43 years (~5 months; $t(51) = -2.37$, $p = 0.022$). Mean Willems dental age was 10.48 ± 1.70 years in boys and 10.80 ± 1.98 years in girls, a non-significant difference of 0.32 years ($t(50) = -0.626$, $p = 0.534$). Girls reached significantly more advanced Björk phalangeal stages than boys (Mann–Whitney $U = 116.00$, $p < 0.001$; mean rank 35.04 vs 17.96); no boy reached stage 5 versus eight girls. Relative to the sex-specific Schops's (1978) reference criteria on Björk, Grave and Brown method, boys attained each stage at a lower chronological and Willems dental age than the reference, whereas girls attained each stage at a higher chronological and dental age than the reference.

Conclusion: Willems method significantly overestimated chronological age, the assessment of phalanx development, determine by the Björk, Grave and Brown method skeletal maturation was markedly more advanced in girls than in boys. Combining dental and hand-wrist skeletal age indicators, rather than chronological age alone, is recommended for individualizing the timing of orthodontic intervention in children 7–12 years old.

Keywords: Dental age, Chronological age, Skeletal age, Willems method, Björk, Grave and Brown method,

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I. INTRODUCTION

Chronological age (CA) - the time elapsed since birth is only a coarse proxy for an individual child's biological maturity. Skeletal and dental development follow their own, partly independent, maturational timetables that can precede or lag behind CA by a year or more, particularly around the pubertal growth spurt [1,2]. For the orthodontist, this discrepancy matters directly: the success of growth-modification and interceptive treatment depends less on how many years a child has lived than on where that child stands on the maturational curve at the moment treatment begins [3,4].

Dental maturity is most often estimated from panoramic radiographs using the staging systems of Demirjian A, et al. [1] or the modification introduced by Willems et al. [2], which recalibrated the original Demirjian maturity scores against a Belgian reference population and expressed the result directly in years rather than as a maturity score. The Willems method has since been tested, and repeatedly shown to over or underestimate CA to a variable degree, in numerous populations, including Chinese [5], Bengali [6], Brazilian [23] and Iranian children, which underlines the need for population-specific validation rather than uncritical transfer of reference values [11,18].

Skeletal maturity is classically assessed from hand-wrist radiographs. Several systems have been proposed, from the comprehensive Greulich-Pyle atlas [12] and the Tanner-Whitehouse (TW2) method [13] to more clinically oriented staging systems such as that of Fishman [10], which tracks a small set of ossification and

epiphyseal-fusion events at defined skeletal sites. Björk, Grave and Brown [7,14] described a comparable staging system based on the development of the phalanges and the adductor sesamoid of the thumb, in which nine sequential stages (PP2 through Ru) are referenced to the timing of the pubertal peak in standing height. This original Björk-Grave-Brown data set was subsequently recalibrated by Schopf in 1978, who derived explicit, sex-specific age criteria (mean chronological age expected at each stage for boys and for girls) from it and, in doing so, quantified for the first time how much earlier girls reach each phalangeal stage relative to boys [8]; Hägg and Taranger [9] later refined these hand-wrist maturational indicators further in relation to the pubertal growth spurt. Because girls enter puberty and complete skeletal maturation earlier than boys, all hand-wrist systems, including the Schopf recalibrated Björk, Grave and Brown criteria, embed sex-specific reference ages [8,9].

Cervical vertebral maturation (CVM), staged on the lateral cephalogram already taken for most orthodontic patients, has become popular as a radiation-sparing alternative to the hand and wrist film, following the methods of Lamparski [16] and the revised staging of Baccetti, Franchi and McNamara [17]. A growing number of recent studies have therefore focused on how well CVM, hand-wrist staging and dental age agree with one another and with CA, and on whether one indicator can substitute for, or usefully complement, another when planning treatment timing [19,20,21,23].

Bulgarian population-specific data relating dental maturity by the Willems method to hand-wrist skeletal maturity assessed by phalangeal staging remain scarce. Establishing how these two commonly available, radiograph-based indicators correspond to one another and to CA in Bulgarian children in mixed to early permanent dentition — the age window in which most decisions about interceptive and functional orthodontic treatment are made — was the rationale for the present study.

AIM

The aim of this study was to assess and compare chronological age, dental age determined by the Willems method, and skeletal maturation determined by the Björk, Grave and Brown hand-wrist method in Bulgarian children aged 7–12 years, and to establish, separately for boys and girls, the chronological and dental age that correspond to each stage of phalangeal maturation.

II. MATERIAL AND METHODS

Study sample

The study sample consisted of 52 children aged 7–12 years (mean CA 10.21 ± 1.37 years, range 7.00–12.89 years) in mixed to early permanent dentition, of whom 26 (50.0%) were boys and 26 (50.0%) were girls. All subjects had an available digital orthopantomographies (OPG) and a left hand-wrist radiograph taken as part of routine orthodontic work-up, with no systemic disease or syndrome known to affect growth or dental development.

Dental age — Willems method

Dental maturity was scored on the seven permanent teeth of the left mandibular quadrant (central incisor to second molar) visible on the OPG, using the eight developmental stages (A–H) originally described by Demirjian et al. [1]. Tooth-specific maturity scores were then converted directly into dental age in years using the sex-specific conversion tables published by Willems et al. [2], giving each child a single Willems dental age (DA-W).

Skeletal age — Björk, Grave and Brown phalangeal method

Skeletal maturation was assessed on the left hand-wrist radiograph by tracking the ossification of the phalanges and the adductor sesamoid according to the hand-wrist maturity (HWM) method of Björk, Grave and Brown [7,14], which defines nine progressive indicators referenced to the pubertal peak in standing height. For the purposes of this study, children were classified into stages 0–5 (0 = before PP2; 1 = PP2; 2 = MP3; 3 = Pisi, H1, R; 4 = S, H2; 5 = MP3cap, PP1cap, Rcap), covering the pre-pubertal and circumpubertal window relevant to the 7–12-year age range studied. The comparison criteria used in this study were the sex-specific age norms established by Schopf's 1978 recalibration of the original Björk, Grave and Brown data [8], which gives, separately for boys and for girls, the mean chronological age at which each stage is expected to be reached and explicitly describes a sex difference in maturational timing girls, according to this recalibration, reach every developmental stage at a younger chronological age than boys.

Statistical analysis

Data were summarized as absolute and relative frequencies for categorical variables and as mean $\pm$ standard deviation, median, range, minimum and maximum for continuous variables. Normality was checked with the Shapiro-Wilk test. Differences between CA and DA within the same children were tested with the paired-samples t-test; differences between boys and girls were tested with the independent-samples t-test (Levene's test for equality of variances) and, for the ordinal Björk, Grave and Brown stage, with the non-parametric Mann-Whitney U test. Associations between chronological age and ordinal maturation stage were examined with

Spearman's rank correlation. A one-sample t-test compared observed CA and dental age at each Björk, Grave and Brown stage with the corresponding sex-specific reference criterion. All tests were two-tailed, with statistical significance set at $\alpha = 0.05$.

III. RESULTS

Sample characteristics

Of the 52 children studied, 26 (50.0%) were boys and 26 (50.0%) were girls (Figure 1 shows the age distribution). The largest age group was the 11-year-olds (16 children, 30.77%), followed by the 10-year-olds (12 children, 23.08%) and the 9-year-olds (10 children, 19.23%); the smallest group was the 12-year-olds (3 children, 5.77%).

Figure 1. Distribution of the study sample by age (n = 52)

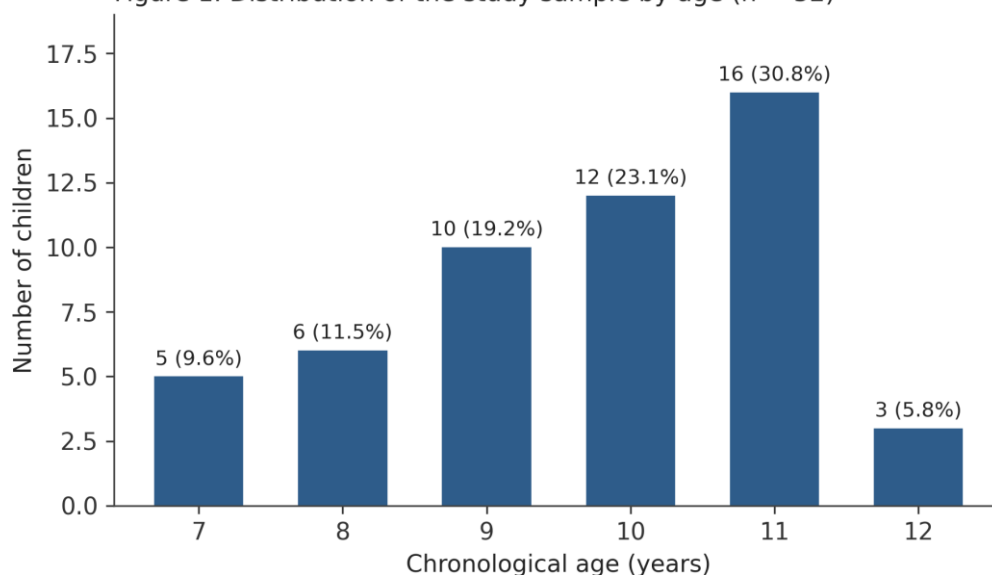


Figure 1. Distribution of the studied children by chronological age (n = 52).

Chronological age versus Willems dental age

The mean chronological age of the 52 children was 10.21 ± 1.37 years (range 7.00–12.89), while the mean Willems dental age was 10.64 ± 1.83 years (range 7.50–15.67) (Table 1, Figure 2). The paired-samples t-test showed that the Willems method overestimated chronological age by a mean of 0.43 years (about 5 months); this difference was statistically significant ($t(51) = -2.37$, $p = 0.022$) (Table 2).

Table 1. Descriptive statistics of chronological age and Willems dental age (years).

Group	N	Chronological age (mean $\pm$ SD)	Willems dental age (mean $\pm$ SD)
Total	52	10.21 ± 1.37	10.64 ± 1.83
Boys	26	10.03 ± 1.50	10.48 ± 1.70
Girls	26	10.39 ± 1.23	10.80 ± 1.98

Table 2. Paired-samples t-test: chronological age vs. Willems dental age.

Group	Mean difference (CA – DA-W), years	SD	t	df	p
Total (n=52)	-0.43	1.32	-2.37	51	0.022*
Boys (n=26)	-0.45	1.41	-1.64	25	0.115
Girls (n=26)	-0.42	1.26	-1.69	25	0.104

* Statistically significant at $\alpha = 0.05$. A negative mean difference indicates that dental age exceeded chronological age.

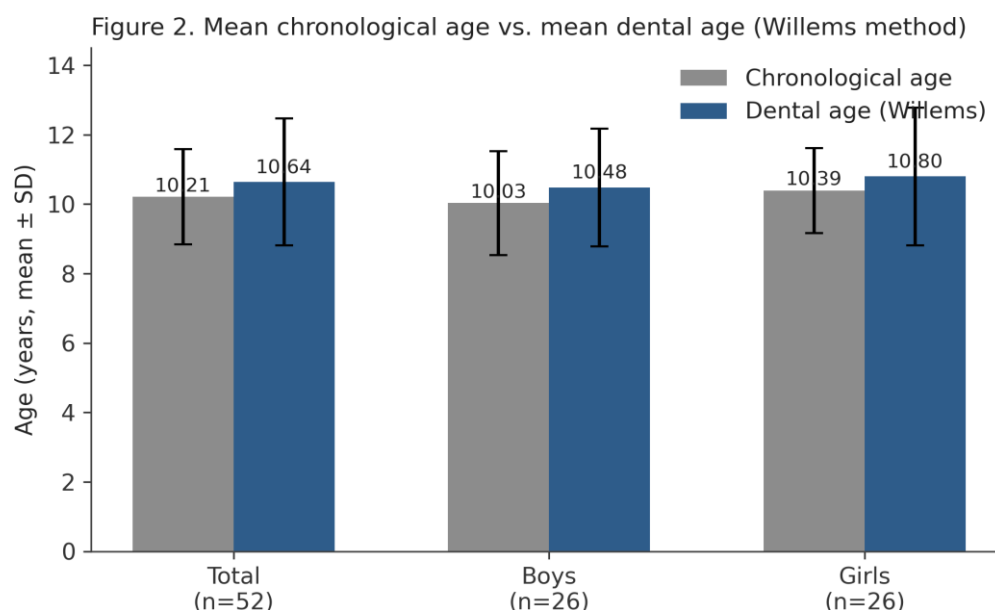


Figure 2. Mean chronological age vs. mean Willems dental age, overall and by sex.

When analyzed separately by sex, the same negative bias was present in both boys (-0.45 years) and girls (-0.42 years), but neither difference reached statistical significance at the smaller subgroup sample size (Table 2). The overestimation of chronological age by the Willems method is therefore a robust finding at the level of the whole sample, while sex-specific subgroup analyses were underpowered to confirm it independently.

Sex differences in Willems dental age

The mean Willems dental age was 10.48 ± 1.70 years in boys and 10.80 ± 1.98 years in girls — a difference of 0.32 years, with girls showing the numerically higher dental age. This difference was not statistically significant (independent-samples t-test, Levene's $p = 0.520$; $t(50) = -0.626$, $p = 0.534$) (Table 3). Chronological age itself also did not differ significantly between boys and girls (mean difference 0.36 years, $p = 0.353$).

Table 3. Independent-samples t-test: comparison of boys and girls.

Indicator	Boys (mean $\pm$ SD)	Girls (mean $\pm$ SD)	Mean diff. (boys – girls)	t (df=50)	p
Chronological age	10.03 $\pm$ 1.50	10.39 $\pm$ 1.23	-0.36	-0.938	0.353
Dental age – Willems	10.48 $\pm$ 1.70	10.80 $\pm$ 1.98	-0.32	-0.626	0.534

Phalangeal maturation stages (Björk, Grave and Brown method) by sex

Distribution across the six phalangeal maturation stages differed markedly between boys and girls (Table 4, Figure 3). Boys were concentrated in the earlier stages: 7 of 26 boys (26.9%) had not yet reached stage 1 (PP2), and a further 10 (38.5%) were in stage 1. Girls were shifted toward later stages: only 1 girl (3.8%) remained before PP2, while 7 girls (26.9%) were in stage 4 (S, H2) and 8 girls (30.8%) had already reached stage 5 (MP3cap, PP1cap, Rcap) — a stage that no boy in the sample had reached. The Mann–Whitney U test confirmed that girls, as a group, were at a significantly more advanced phalangeal maturation stage than boys ($U = 116.00$, $p < 0.001$; mean rank 35.04 in girls vs. 17.96 in boys).

Table 4. Distribution of phalangeal maturation stages (Björk method) by sex.

Björk stage	Boys (n)	Girls (n)	Total (n)	% of sample
0 – Before PP2	7	1	8	15.38
1 – PP2	10	4	14	26.92
2 – MP3	5	2	7	13.46
3 – Pisi, H1, R	1	4	5	9.62

Björk stage	Boys (n)	Girls (n)	Total (n)	% of sample
4 – S, H2	3	7	10	19.23
5 – MP3cap, PP1cap, Rcap	0	8	8	15.38
Total	26	26	52	100.00

Mann–Whitney U test for stage by sex: U = 116.00; mean rank boys = 17.96, girls = 35.04; p < 0.001.

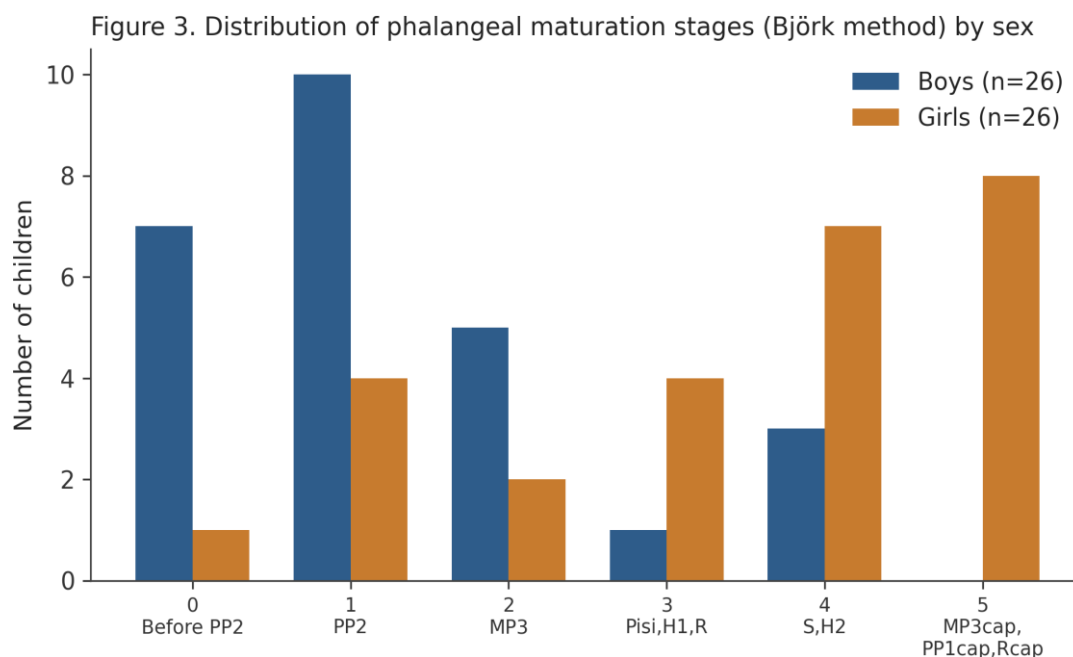


Figure 3. Distribution of phalangeal maturation stages (Björk, Grave and Brown method) by sex.

Correspondence between phalangeal stage and chronological / dental age, by sex

Table 5 compares, for each attainable phalangeal stage, the observed mean chronological age of boys and girls in the present sample with the sex-specific reference age proposed by Björk. In every stage from 1 to 4, boys reached the stage at a chronological age below the Björk reference (differences of -0.58 to -1.31 years), whereas girls reached the same stages at a chronological age above the reference (differences of $+0.07$ to $+0.89$ years). No boy in the sample had reached stage 5, while 8 girls had, at a mean chronological age of 11.57 years — 0.57 years above the 11.00-year reference for girls.

Table 5. Observed chronological age at each Björk phalangeal stage vs. Schopf's (1978) sex-specific Björk reference criteria.

Björk stage	Sex	n	Schopf/Björk criterion (years)	Observed mean CA (years)	Difference (years)
1 – PP2	Boys	10	10.60	10.02	-0.58
1 – PP2	Girls	4	8.10	8.95	$+0.85$
2 – MP3	Boys	5	12.00	11.01	-0.99
2 – MP3	Girls	2	8.10	8.99	$+0.89$
3 – Pisi, H1, R	Boys	1	12.60	12.89	$+0.29$
3 – Pisi, H1, R	Girls	4	9.60	10.29	$+0.69$
4 – S, H2	Boys	3	13.00	11.69	-1.31
4 – S, H2	Girls	7	10.60	10.67	$+0.07$

Björk stage	Sex	n	Schopf/Björk criterion (years)	Observed mean CA (years)	Difference (years)
5 – MP3cap, PP1cap, Rcap	Boys	0	14.00	—	—
5 – MP3cap, PP1cap, Rcap	Girls	8	11.00	11.57	+0.57

The same pattern held when dental age by the Willems method was used instead of chronological age (Table 6): boys reached stages 1–3 at a Willems dental age below the Schopf/Björk, Grave and Brown reference, while girls reached every stage at a Willems dental age at or above the reference — most markedly at stage 5, where the observed mean dental age of girls (12.82 years) exceeded the 11.00-year reference for girls by 1.82 years.

Table 6. Observed Willems dental age at each Björk phalangeal stage vs. Schopf's (1978) sex-specific Björk reference criteria.

Björk stage	Sex	n	Schopf/Björk criterion (years)	Observed mean DA-Willems (years)	Difference (years)
1 – PP2	Boys	10	10.60	10.17	–0.43
1 – PP2	Girls	4	8.10	8.94	+0.84
2 – MP3	Boys	5	12.00	11.43	–0.57
2 – MP3	Girls	2	8.10	8.58	+0.48
3 – Pisi, H1, R	Boys	1	12.60	12.25	–0.35
3 – Pisi, H1, R	Girls	4	9.60	9.42	–0.18
4 – S, H2	Boys	3	13.00	13.19	+0.19
4 – S, H2	Girls	7	10.60	11.31	+0.71
5 – MP3cap, PP1cap, Rcap	Boys	0	14.00	—	—
5 – MP3cap, PP1cap, Rcap	Girls	8	11.00	12.82	+1.82

Figure 4. Observed chronological and Willems dental age compared with Björk phalangeal reference criteria, by stage and sex

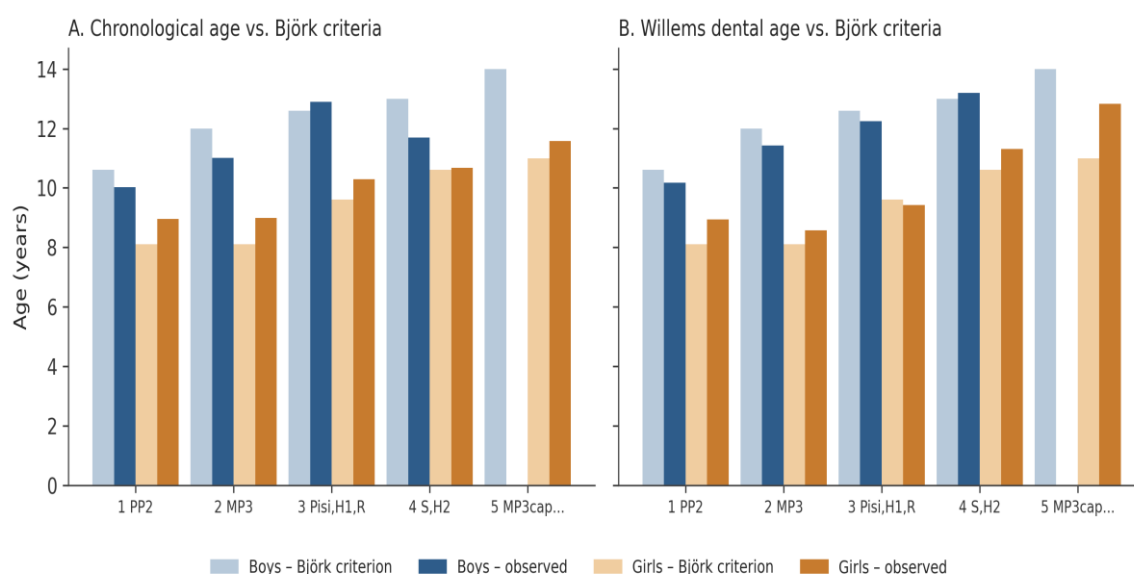


Figure 4. Observed chronological age (A) and Willems dental age (B) compared with Schopf's (1978) sex-specific Björk phalangeal reference criteria, by stage.

Overall, phalangeal maturation stage correlated very strongly with hand-wrist skeletal age determined by the Lamparski and Baccetti cervical-vertebral-derived staging used elsewhere in the parent study (Spearman $\rho = 0.845$ for both, $p < 0.001$), confirming that the Björk phalangeal indicators and standard skeletal-age staging track the same underlying maturational process in this sample.

IV. DISCUSSION

The present findings add Bulgarian population data to a growing, and still heterogeneous, international literature on the accuracy of the Willems method. On average, the method overestimated chronological age in our sample by 0.43 years - a modest but statistically significant bias that is well within the range reported elsewhere: a Chinese radiographic study found a comparable pattern of over- and under-estimation depending on age group and sex [5], while a Bengali cohort study comparing the Willems and Cameriere methods likewise reported small but systematic deviations from chronological age [6]. A 2026 cross-sectional comparison of the Demirjian and Willems methods in exactly the 7–12-year age band studied here similarly found that the two systems diverge from chronological age in opposite directions, with Willems tending toward overestimation, echoing the direction of bias we observed [18]. Taken together with the meta-analysis by Esan et al., which pooled dozens of validation studies and concluded that neither Demirjian's nor Willems' original reference values transfer uniformly across populations [11], our results reinforce the case for population-specific calibration before either method is used forensically or clinically in Bulgarian children.

That the sex difference in Willems dental age (0.32 years, favoring girls) did not reach statistical significance is broadly consistent with the original Belgian validation, which found only limited sex dimorphism in dental maturation scores [2]; it also mirrors the more modest sex effect typically reported for dental, as opposed to skeletal, maturity indicators [18]. This stands in useful clinical contrast to the skeletal findings of the present study, where the sex effect was large and highly significant: girls occupied markedly more advanced Björk phalangeal stages than boys ($U = 116.00$, $p < 0.001$), and eight girls — but no boy — had already reached the terminal stage examined (MP3cap, PP1cap, Rcap). This asymmetry between a fairly sex-neutral dental clock and a strongly sex-dimorphic skeletal clock is exactly what Schopf's 1978 recalibration of the Björk–Grave–Brown data predicts: by attaching an explicit, sex-specific mean age to each phalangeal stage, Schopf's criteria quantitatively encode the observation — confirmed in our sample — that girls reach every stage at a younger chronological age than boys [8,9]. The same asymmetry has recently been reaffirmed in comparative work using cervical vertebral maturation alongside hand-wrist indicators and dental age in the same patients, which likewise found skeletal indicators to separate the sexes far more sharply than dental age does [20,21].

The comparison against the Schopf-recalibrated, sex-specific Björk reference ages is, we believe, the most clinically informative part of the study. Boys in our sample reached phalangeal stages 1 through 4 at a chronological (and, largely, dental) age below the Schopf/Björk criteria for boys, while girls reached the same stages at an age above the (lower) criteria set for girls. Rather than indicating that Bulgarian boys mature skeletally earlier and Bulgarian girls later than the historical Central European reference population on which Schopf's recalibration was based, this pattern most plausibly reflects the compressed, sex-mixed stage distribution inherent to a moderate sample size — the reference ages were derived from much larger, single-sex longitudinal cohorts, so any deviation should be interpreted as a call for larger confirmatory samples rather than a substantive secular or population shift [7,8]. What the data show unambiguously, and consistently with both Schopf's original criteria and the CVM literature [4,15], is that girls attain each phalangeal maturational milestone at a systematically younger age than boys reach the equivalent milestone, underscoring that orthodontic treatment timing decided by calendar age alone risks under-treating early-maturing girls and over-treating late-maturing boys relative to their true skeletal window.

The very strong correlation we found between phalangeal (Björk) stage and cervical-vertebra-based skeletal age (Spearman $\rho = 0.845$ for both the Lamparski and the Baccetti staging) is consistent with recent retrospective comparisons showing good, though not perfect, agreement between hand-wrist and cervical vertebral maturation indicators in growing orthodontic patients [20,21], and with the meta-analytic evidence that Baccetti-staged cervical maturation maps onto a fairly narrow chronological age range at each stage [19]. Because a lateral cephalogram or a panoramic radiograph is already part of most orthodontic records, while a dedicated hand-wrist film adds radiation exposure and cost, this convergence supports using dental and cervical vertebral maturation together as a practical proxy for hand-wrist skeletal age in everyday practice, reserving direct hand-wrist assessment (Björk/Schopf, Fishman or Greulich–Pyle staging) for cases where growth prediction is particularly critical [10,12]. Interest in automating exactly this kind of multi-indicator staging is growing rapidly: recent artificial-intelligence models have been trained to predict Fishman skeletal maturity indicators directly from hand-wrist images [24], and a 2025 comparative study evaluated deep-learning classification across five different hand-wrist staging systems simultaneously [23], suggesting that some of the practical burden of skeletal-age assessment may be reduced by automated tools in the near future.

Several limitations temper these conclusions. The sample of 52 children, while adequate to detect the overall dental-age bias, left some Björk-stage-by-sex cells — most notably stage 5 in boys, which was empty — too sparse for robust one-sample comparisons against the reference criteria. The design was cross-sectional, so maturational tempo (the rate of progression through stages) could not be assessed directly, and the sample was drawn from a single Bulgarian center, which limits generalizability to the wider national or regional population. Longitudinal, multi-center studies with larger sex- and age-stratified subgroups are needed to derive Bulgarian-specific Willems and Björk reference values with adequate precision.

V. CONCLUSION

In this sample of Bulgarian children aged 7–12 years in mixed to early permanent dentition, the Willems method significantly overestimated chronological age by an average of 0.43 years, although the direction of this bias was consistent, but not individually significant, in both sexes. Dental age by the Willems method did not differ significantly between boys and girls, whereas phalangeal skeletal maturation staged by the Björk method was significantly more advanced in girls, who reached every maturational stage-including the most advanced stage assessed-earlier and more frequently than boys. Chronological and dental age at each Björk stage diverged from the classic sex-specific reference criteria in opposite directions for boys and girls, and phalangeal stage correlated very strongly with hand-wrist equivalent skeletal age derived from cervical vertebral maturation. These findings support combining dental radiographic age with skeletal maturity indicators, rather than relying on chronological age alone, when individualizing the timing of interceptive and functional orthodontic treatment in Bulgarian children- with particular attention to the earlier skeletal maturation window in girls.

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