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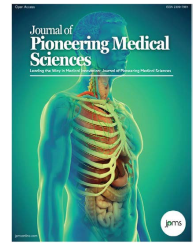

Validity and Reliability of Skeletal Maturity Assessment Using South Indian Objective Method in Maharashtrian Population

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Abstract: Background: Because cervical vertebrae undergo measurable shape changes during somatic growth, lateral cephalograms may provide a practical estimate of skeletal maturity without additional hand-wrist radiation. This cross-sectional validation study evaluated whether an objective cervical vertebral bone age (CVBA) formula derived in a South Indian population is applicable to Maharashtrian children aged 9-16 years (N = 300). **Methods:** CVBA was calculated from C3 and C4 vertebral ratios on lateral cephalograms and compared with chronological age (CA) and hand-wrist bone age (TW3 method). **Results:** CVBA showed strong correlation with hand-wrist bone age in both sexes (males r = 0.907; females r = 0.953), but mean differences remained significant across CA, CVBA, and hand-wrist bone age on ANOVA/Tukey testing. **Conclusion:** Thus, employing newly derived equations exclusively for the Maharashtrian population would be beneficial to avoid erroneous skeletal maturity assessment. Population specificity should be emphasized when using formula based methods for bone age estimation.

Key Words: Skeletal Maturity, CVBA, BA, Maharashtrian Population, Ethnic Variation, Regression Formula, Objective Method

INTRODUCTION

The conventional hand-wrist radiograph remains a widely used indicator of skeletal maturity, but it requires additional radiation exposure in growing orthodontic patients [1-3]. Cervical vertebral maturation (CVM) assessed on the routine lateral cephalogram is attractive because the vertebral bodies remodel during puberty in response to systemic skeletal growth, allowing maturity estimation without a separate hand-wrist exposure [4-7]. However, conventional CVM staging has long been criticized for observer subjectivity, limited reproducibility, and uncertainty at stage boundaries [2,4,5]. These concerns have encouraged the development of objective CVBA approaches based on vertebral measurements and regression formulae rather than purely visual staging [1,5,8].

METHODS

This cross-sectional validation study included 600 orthodontic patients (300 males and 300 females) aged 9-16 years from six administrative divisions of Maharashtra. The pubertal age window was selected because this is the period in which orthodontic growth-modification decisions are most sensitive to skeletal maturity status. Participants were selected using simple random sampling from available eligible records containing both a lateral cephalogram and a hand-wrist radiograph.

Selection criteria included Maharashtrian origin, good general health, and absence of facial, cervical, or wrist trauma; congenital or acquired cervical spine abnormalities; syndromic growth disturbance; or known hormonal disorders. Maharashtrian origin and nutritional adequacy were based on the source clinical records available to the investigators. Because the present manuscript is based on the available study file, detailed data on BMI, pubertal markers, and socioeconomic variables were not available for analysis and are acknowledged as limitations.

Measurements were made on the C3 and C4 vertebrae after calibration with Webceph software (Figure 1). The linear

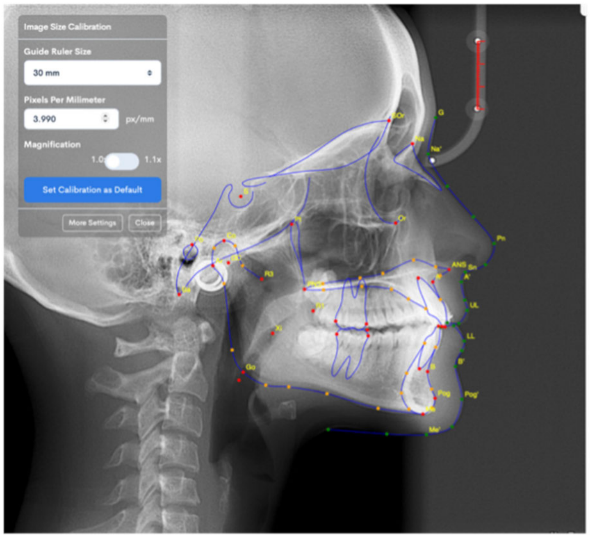

Figure 1: Calibration on Webceph Software

Ratios	Parameters assessed
AH/AP	Anterior height/anteroposterior width
MH/AP	Middle height/anteroposterior width
PH/AP	Posterior height/anteroposterior width
AH/PH	Anterior height/posterior height
AH/MH	Anterior height/middle height
MH/PH	Middle height/posterior height
CONC/MH	Depth of concavity/middle height

Figure 2: Ratios

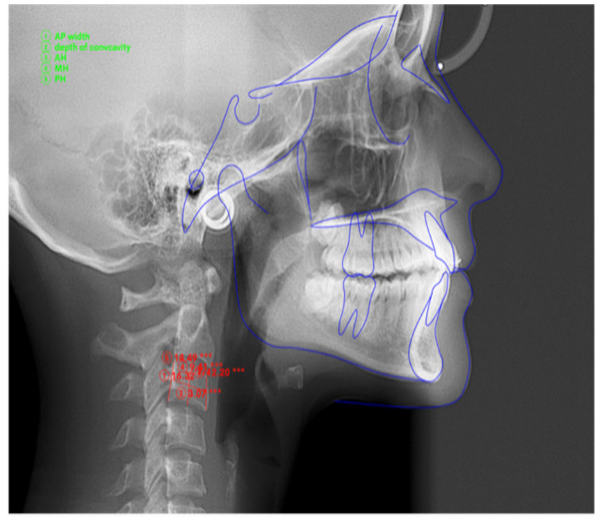

Figure 3: Landmarks Marked on C3 Vertebrae on Webceph Software

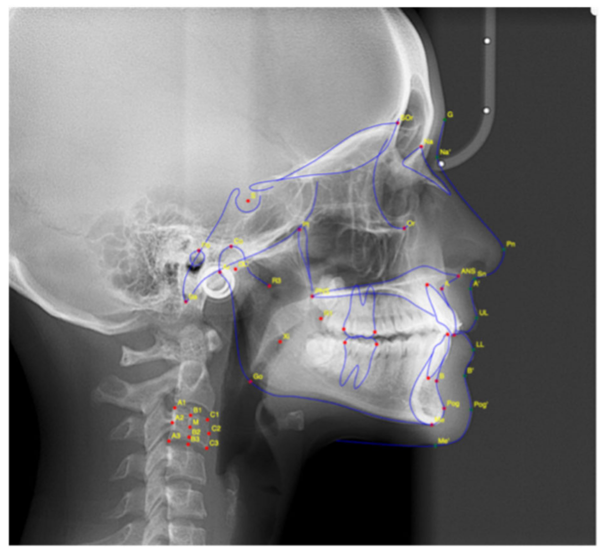

Figure 4: Linear Measurements used to Calculate Ratios on Webceph Software

Table 1: Formula used for CVBA

Cervical vertebral bone age (CVBA)	Formula
For female	0.774+(4.033 × PH3/AP3)−(0.087 × H3/AP3)+(2.26 × AH3/AP3)−(2.126 × AH4/AP4)+(8.513 × AH4/H4)
For Male	7.137+(3.695 × AH3/AP3)−(1.582 × H3/AP3)+(8.716 × CONC3/H3)+(1.753 × AH4/AP4)+(1.604 × H4/AP4)

measurements and seven ratios were calculated according to the South Indian objective formula proposed by Chandrasekar et al. [1] (Figures 2-4; Table 1). CVBA values were then compared with bone age assessed by the Tanner-Whitehouse 3 (TW3) hand-wrist method and with chronological age. The study question was whether the south indian population formulas are valid for bone age estimation in Maharastrian children.

Statistical analysis included descriptive statistics, one-way ANOVA to detect significant differences among CA, CVBA, and hand-wrist bone age, Tukey's post-hoc testing for pairwise differences, and Pearson's correlation coefficient to quantify interrelationships at a 5% significance level. The current dataset supports correlation-based validation; however, agreement analyses such as Bland-Altman plots, effect-size estimates, and formal intra-/inter-examiner ICC values were not available in the source file and should be incorporated in future validation studies.

RESULTS

Average age values are summarized in Table 2. In males, hand-wrist bone age showed the strongest relationship with

Table 2: Mean±SD of Different Ages

Ages	Mean±SD	
	Males	Females
CA	12.659±1.652	12.347±2.423
CVBA	11.576±1.345	12.727±1.571
Hand- wrist BA	13.107±1.634	12.462±1.766

Table 3: Inter-Relationships Between Different Ages

Ages	Inter-relationships between different ages			
	Avg. Diff. (years)		Pearson's correlation coefficients (r)	
CA and CVBA	1.509±0.883	1.178±0.853	0.704	0.779
CA and Hand- wrist BA	0.496±0.350	1.102±0.759	0.689	0.801
CVBA Hand -wrist BA	1.577±1.096	0.406±0.440	0.907	0.953

Table 4: ANOVA Test

Ages	Inter-relationships between different ages				
Differences observed across different age groups	df	MSS	F- ratio	p-value	Inference
Male	2	16.93	6.27	0.002	Significant difference
Female	2	17.17	6.77	0.009	Significant difference

CVBA (r = 0.907), followed by CA (r = 0.704), while the relationship between CA and hand-wrist bone age was weaker (r = 0.689) (Table 3). In females, the same pattern was observed, with the strongest correlation again between hand-wrist bone age and CVBA (r = 0.953). ANOVA demonstrated significant differences among CA, CVBA, and hand-wrist bone age in both sexes (males: F = 6.27, p = 0.002; females: F = 6.77, p = 0.009), and Tukey post-hoc testing showed significant pairwise differences among the compared age measures (Table 4). These findings indicate that the South Indian formula tracks maturity strongly, but not interchangeably, in this Maharashtrian sample.

DISCUSSION

The present study evaluated a quantitative CVBA method during the circumpubertal period, when orthodontic timing decisions are most clinically relevant. By using measurable vertebral body ratios rather than purely visual staging, the method reduces - but does not eliminate - subjectivity, because landmark identification and tracking remain examiner-dependent [2,4,5]. The high correlation between hand-wrist bone age and CVBA in both sexes supports the usefulness of cephalogram-based skeletal maturity estimation in Maharashtrian children. At the same time, the significant mean differences observed on ANOVA and Tukey testing show that correlation alone should not be interpreted as direct agreement or interchangeability. This distinction is clinically important because a method can correlate well while still systematically overestimating or underestimating maturity.

A sex-related performance difference was evident, with a larger male gap between CVBA and hand-wrist bone age. From a clinical standpoint, underestimation of maturity in boys could delay treatment decisions if the formula is transferred without recalibration. Similar cross-population concerns have been reported in studies evaluating CVM, TW3, and other bone-age methods across different racial and ethnic groups [10-20]. Regional differences in growth tempo may reflect interactions among genetics, nutrition, secular trend, and socioeconomic environment, which is why formulae developed in one Indian population may not be directly transferable to another [1,10,17,21]. The present findings therefore support the use of population-specific Maharashtrian equations rather than direct reuse of the South Indian formula for routine decisions.

CONCLUSION

Our study confirms the validity of CVBA estimation, but its population specificity is also emphasized. The new Maharashtrian equations so developed should be used on specific population. Future studies need to standardize procedures and automate techniques, develop formulas in other populations, without racial differences. In routine orthodontic practice, CVBA can serve as a useful supportive maturity indicator on the cephalogram, potentially reducing the need for additional radiation, but future work should add multicenter validation, agreement metrics, and automation before widespread clinical adoption.

Limitations

Agreement analysis (for example Bland-Altman plots), age-band accuracy measures, and formal examiner reliability indices were not available in the source manuscript. In addition, potential confounders such as BMI, pubertal status, and socioeconomic variables were not available for the present analysis.

Ethics and Reporting Note

The source file did not provided an ethics approval number, consent/assent statement, data-availability statement, or STROBE reporting declaration. These items should be inserted from the original study records before journal resubmission.

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