Original Article

A Comparison of Hand-wrist Bone and Cervical Vertebral Analyses in Measuring Skeletal Maturation

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ABSTRACT

Objective: To compare skeletal maturation as measured by hand-wrist bone analysis and by cervical vertebral analysis.

Materials and Methods: A radiographic hand-wrist bone analysis and cephalometric cervical vertebral analysis of 30 patients (14 males and 16 females; 7–18 years of age) were examined. The hand-wrist bone analysis was evaluated by the Bjork index, whereas the cervical vertebral analysis was assessed by the cervical vertebral maturation stage (CVMS) method. To define vertebral stages, the analysis consisted of both cephalometric (13 points) and morphologic evaluation of three cervical vertebrae (concavity of second, third, and fourth vertebrae and shape of third and fourth vertebrae). These measurements were then compared with the hand-wrist bone analysis, and the results were statistically analyzed by the Cohen κ concordance index. The same procedure was repeated after 6 months and showed identical results.

Results: The Cohen κ index obtained (mean $\pm$ SD) was 0.783 ± 0.098, which is in the significant range. The results show a concordance of 83.3%, considering that the estimated percentage for each case is 23.3%. The results also show a correlation of CVMS I with Bjork stages 1–3 (interval A), CVMS II with Bjork stage 4 (interval B), CVMS III with Bjork stage 5 (interval C), CVMS IV with Bjork stages 6 and 7 (interval D), and CVMS V with Bjork stages 8 and 9 (interval E).

Conclusions: Vertebral analysis on a lateral cephalogram is as valid as the hand-wrist bone analysis with the advantage of reducing the radiation exposure of growing subjects.

KEY WORDS: Growth evaluation; Cervical vertebrae

INTRODUCTION

The timing of growth for facial bones and the periods of accelerated or intense physiologic growth must be individualized to better exploit bone remodeling for correcting skeletal discrepancies. The classical and most widely used method for skeletal-age evaluation is the highly reliable hand-wrist bone analysis performed by radiograph. However, this analysis entails further exposure to ionizing radiation in addition to the routine radiographic records required for an orthodontic patient.

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The validity of the hand-wrist bone analysis has been confirmed by numerous studies. In the 1950s, Greulich and Pyle, with the aid of radiographs, reported a precise sequence of hand and wrist bone ossification. Their atlas was updated in 1959 and has so far remained the most authoritative publication for the analysis of hand ossification for establishing skeletal age.[1] Further work was conducted by Bjork,[2] Rakosi et al,[3] Grave and Brown,[4] and Giannì.[5]

Analysis of possible differences of skeletal maturation according to gender had a negative outcome, as highlighted by Grave and Brown[4] and by Kimura.[6] Kimura pointed out that male and female growth follows a similar process until 8 years of age. After this age, girls experience a precocious acceleration of growth, demonstrated by the fact that girls' hand bones reach full maturity at age 16 as compared with age 18 for boys.

Silveria et al[7] demonstrated through the analysis of hand-wrist bone analyses that, during the early and intermediate stages of skeletal maturity, the mandible and maxilla show a similar growth rate. However, in

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the final stages of skeletal maturity, mandibular growth exceeds that of the maxilla.

In 1980, Smith[8] reviewed the literature and confirmed the efficacy and diagnostic validity of the hand-wrist bone analysis. Regarding the possible relationship between skeletal and chronological age, Fishman[9] found no close relationship and concluded that there was no specific relation between the variables.

The assessment of the degree of cervical vertebral maturation (CVM)[10–15] is another method of assessing skeletal maturation. This method has not been studied closely but does show a great potential to determine the skeletal age of the patient. In fact, the maturation of the cervical vertebrae follows given stages of ossification from which the skeletal maturity of the patient can be deduced.

Lamparski[11] studied the development of the cervical vertebrae and demonstrated the efficacy of the CVM method in assessing skeletal age. In addition, Lamparski established a series of standards to assess skeletal age in males and females, highlighting the 6 stages of maturation.

O'Reilly and Yanniello[12] undertook a study that compared Lamparski's stages of growth of cervical vertebrae with mandibular maturation. They reported a correlation between the stages of CVM and the stages of mandibular growth that characterize puberty.

The use of a lead collar to protect the thyroid may hinder full vision of the cervical spine. Therefore, in 1995, Hassel and Farman[13] compiled a new index of CVM, which evaluated the visible lateral profiles of the second, third, and fourth cervical vertebrae. They established 6 categories similar to those identified by Lamparski.[11] These categories were also closely related to the stages of skeletal maturity identified by Fishman[16] and based on hand bones. The authors concluded that changes in the shape of vertebrae (concavity of the inferior edge and vertical height) can help determine skeletal maturity and residual growth potential. Garcia-Fernandez et al[17] demonstrated that this method was valid regardless of the race of the subjects analyzed.

In 2000, Franchi et al[14] studied the records of 24 individuals in the University of Michigan Ann Arbor Elementary and Secondary School Growth Study to confirm the validity of the CVM method for assessing mandibular growth. At the same time, their study evaluated the increases in stature associated with the maturation of the cervical vertebrae. The authors reported that the peak of statural growth corresponds to the peak of mandibular growth. In 2002, Baccetti et al[15] devised the CVM method that we applied in our study. The aim of the present study is to evaluate the possible concordance between hand-wrist bone analysis and cervical vertebral analysis measured on lateral skull cephalograms.

MATERIALS AND METHODS

The present study involved 30 patients (14 males and 16 females, 7–18 years of age) undergoing orthodontic treatment. A hand-wrist bone analysis and a cervical vertebral analysis were available for all patients and determined their skeletal age.

This same determination was performed on the same radiographs after 6 months by the same operator to confirm the repeatability of the obtained results. The hand-wrist bone analysis was evaluated according to the Bjork index.[2,3] Hand-wrist bone mineralization was evaluated up to the age of 9 years; thereafter, the mineralization of the metacarpal and phalanx bones was used.

The pubertal peak growth phase is related to mineralization of the sesamoid bone at the metacarpal phalanx articulation of the thumb (phase S) and when the fusion for ossification of the hook-bone occurs at the hand-wrist level (phase H2) (stage 4).

The peak of growth coincides with the capping of the epiphysis on the diaphysis of the medial phalanx of the middle finger (phase MP3 cap), the thumb's proximal phalanx (phase PP1 cap), and by the radius (phase R cap) (stage 5). The deceleration phase takes place when fusion starts at the epiphysis on the diaphysis of the middle finger's distal phalanx (stage DPU or stage 6).

The cervical vertebral analysis was assessed by the Baccetti et al[15] CVM method, which, when compared with the other cervical vertebral–evaluating methods, presents the following advantages: (1) appraises three vertebrae only, (2) restricts the stages of growth, and (3) uses simpler and easily individuated cephalometric points.

The stages of skeleton maturation assessed through the cervical vertebrae were codified through the CVM stage (CVMS) method followed by Roman numerals to define the skeleton maturation stages. Only 3 vertebrae were appraised (C2, C3, and C4). This method is composed of the following 5 stages:

- CVMS I: Marked out by flat inferior edges. The C2 inferior edge can present a small cavity, and C3 and C4 are trapezoidal (their posterior height is shorter than the anterior). The mandible growth will reach its peak 1 year after this stage with a 6-month margin of error.
- CVMS II: Concavities appear even on the C3 inferior edge. C3 and C4 can still present a sort of trapezoidal or even horizontal rectangular form (the larger base of the rectangle is horizontal). It marks the onset of the maximum mandible spurt; therefore, 90%

of the patients will reach the peak of mandibular growth within 1 year.

- CVMS III: Marked by concavities under C4. C2, C3, and C4 bodies are on the lower edge. C3 and C4 bodies are horizontal rectangles. This stage is the simplest to be checked and marks the end of the maximum growth-spurt year. Therefore, the peak of maximum acceleration has just passed.
- CVMS IV: At least one of the two cervical vertebrae (C3 and C4) or even both have a square feature. The concavity on the inferior edge of C2, C3, and C4 is always present. The mandibular acceleration peak ended at least 1 year earlier.
- CVMS V: At least one vertebra (C3 and C4) or even both have a vertical rectangular form (the larger base of the rectangle is vertical). The inferior edge concavity of C2, C3, and C4 is always present. The mandibular accelerated growth ended 1 year earlier.

The peak of growth is always achieved between CVMS II and CVMS III. During this stage the mandible grows 5.5 mm, and before and after this stage it grows by about 2–2.5 mm. The cervical vertebral margin of error can be about 6 months.

According to the hypothesis that the analysis of cervical vertebrae stages was made before or during the peak of growth (CVMS I–III), we would be able to produce skeletal changes during these periods. By contrast, after the peak of growth (CVMS IV, V), therapy will induce only dentoalveolar modifications.

The indicators of each individual's maturity as measured by both Bjork[2] and Grave and Brown[4] were compared with the CVMS methods by using the Cohen κ concordant index. This was done to assess interrater reliability when observing categorical variables (ie, two different classifications tied to the same category, the skeletal age). To apply the Cohen κ index, the stages of growth were reduced to five intervals (A–E) to relate the five stages of the CVMS method to the nine stages of a Bjork hand-wrist bone analysis. This reduction from nine to five stages does not entail the loss of significant data, as the goal is not represented by the identification of each single stage but by the intervals of growth.

- Interval A: The stage of growth preceding the pubertal acceleration peak, corresponding to Bjork stages 1–3.
- Interval B: The stage of acceleration growth to get to the peak, corresponding to Bjork stage 4.
- Interval C: The peak of growth stage, corresponding to Bjork stage 5.
- Interval D: The phase of the progressive slowing of growth, corresponding to Bjork stages 6 and 7.
- Interval E: The growth is completed. It represents the beginning of the adult age and corresponds to Bjork stages 8 and 9.

RESULTS

The results of the cervical vertebral analysis and the hand-wrist bone analysis for the 30 patients are shown in Tables 1 and 2. Table 1 illustrates the data of the first evaluation, and Table 2 summarizes the data obtained on the same radiographs after 6 months.

The Cohen κ index was calculated by considering the most unfavorable conditions ranging between the uncategorized cases of hand-wrist bone analysis and those of the vertebral analysis (ie, when the stage of growth is midway between two adjacent stages). For example, patient T.M. = CVMS IV–V or patient M.A. = Bjork 3–4 and those in which the CVMS evaluation and Bjork index do not match (eg, subject M.E. = CVMS III Bjork 9). Both of these were considered discordant. Under the first evaluation, three cases were uncategorized by the evaluation (B.G., M.A., T.M.) and two discordant cases (M.E., B.M.) occurred. Under the second evaluation (made on the same radiographs 6 months after the first evaluation), two uncategorized (M.A., T.M.) and three conflicting cases (B.G., M.E., B.M.) occurred.

- CVMS I with Bjork stages 1–3 (interval A)
- CVMS II with Bjork stage 4 (interval B)
- CVMS III with Bjork stage 5 (interval C)
- CVMS IV with Bjork stages 6 and 7 (interval D)
- CVMS V with Bjork stages 8 and 9 (interval E)

The comparison of the five-stage CVMS method, Bjork's five intervals of growth (A–E), and Cohen κ index leads to a concordance value (mean ± SD) of 0.783 ± 0.098. Given that the maximum value of the concordance index is 1.00, an outcome between 0.6 and 0.8 is fairly good.

The results show a concordance of 83.3%, considering that 23.3% is the estimated percentage for each case. The evaluation made 6 months after led to the same results. The case of patient B.G. represents the only difference between the first and the second evaluation. In fact, in the first evaluation it was classified as CVMS I–II and a Bjork 4 unclassified case, whereas in the second evaluation it was classified as a CVMS I and Bjork 4 discordant case.

DISCUSSION

In dentofacial orthopedics, each patient's skeletal maturation period is important in order to better exploit the growth potential by using functional therapy. The rate of facial growth, as emphasized by an analytic study of the published bibliography, is correlated with both statural growth and skeletal maturation.[18] Age is

TABLE 1. Cervical Vertebrae Measurements, Cervical Vertebral Maturation Stage (CVMS) Stages, and Hand-Wrist Bone Bjork Stages With Related Intervals* (conc = concavity)

Patient	C2 conc (mm)	C3 conc (mm)	C4 conc (mm)	P3 B3 A3	P4 B4 A4	C3 BAR	C3 PAR	C4 BAR	C4 PAR	CVMS	Bjork
N.A.	0	0	0	11-16-7	12-16-9	2.28	1.57	1.77	1.33	I	1 A
S.M.	1	0	0	8-12.5-6	9.5-13-7	2.08	1.33	1.85	1.35	I	1 A
V.F.	0	0	0	11-13-8	10-13-8	1.62	1.37	1.62	1.25	I	1 A
V.O.	1	0	0	12-14-8	11-14-8	1.75	1.5	1.75	1.37	I	1 A
B.A.	0	0	0	9-15-8	10-15-7	1.87	1.12	2.14	1.42	I	2 A
M.M.	1.5	0	0	11-14-8	12-14-7	1.75	1.37	2	1.71	I	2–3 A
M.C.	1	0	0	11.5-16-8	12-15-9	2	1.43	1.66	1.33	I	3 A
G.M.	0	0	0	12-15-9	12-15-9	1.66	1.33	1.66	1.33	I	3 A
B.G.	*1*	*0.3*	*0*	*11-14-10*	*12-15-9*	*1.4*	*1.1*	*1.66*	*1.33*	*I–II*	*4 B*
M.A.	*1*	*1*	*0*	*10-14-7*	*9-15-7*	*2*	*1.42*	*2.14*	*1.28*	*II*	*3–4 A–B*
G.A.	1.5	1	0	12-15-9	12-16-9	1.66	1.33	1.77	1.33	II	4 B
M.S.	2	1	0	12-16-9	10-14-9	1.77	1.33	1.55	1.11	II	4 B
D.N.	1	1	0	10-13.5-8.5	10-13-10	1.58	1.17	1.3	1	II	4 B
T.T.	1	1	0	14-15-10	12-14-9	1.5	1.4	1.55	1.33	II	4 B
V.M.	2	1	0	12-15-9	12-15-9	1.66	1.33	1.66	1.33	II	4 B
T.A.	1	1	0	11-16-8	11-17-9	2	1.37	1.88	1.22	II	4 B
M.M.	1.5	2	1	13-15-10	13-15-9	1.5	1.3	1.66	1.44	III	5 C
T.S.	3	2	2	10-14-9	12-13-10	1.55	1.11	1.3	1.2	III	5 C
C.G.	1	1.5	1.5	11-14-10	12-14-10	1.4	1.1	1.4	1.2	III	5 C
M.A.	2.5	2	2	13-18-10	12-19-10	1.8	1.3	1.9	1.2	III	5 C
M.B.	1.5	2	1	14-12-12	13-13-10	1	1.07	1.3	1.3	III	5 C
G.C.	2	1.5	1	13-13-10	12-13-9	1.3	1.3	1.44	1.33	III	5 C
V.E.	2	1.5	2	12-14-11	13-15-11	1.27	1.09	1.36	1.18	III	5 C
M.E.	**3**	**2.5**	**3**	**14-15-13**	**15-16-13**	**1.15**	**1.07**	**1.23**	**1.15**	**III**	**9 E**
N.F.	2	3	2	14-14-14	14-14-13	1	1	1.07	1.07	IV	6 D
T.M.	*2.5*	*3*	*3*	*14-13-14*	*14-14-13*	*0.92*	*1*	*1.07*	*1.07*	*IV–V*	*8 E*
B.M.	**1**	**2**	**2**	**15-14-14**	**16-13-14**	**1**	**1.07**	**0.92**	**1.14**	**V**	**6 D**
B.E.	1.5	1	1.5	15-13-14	15-12-11	0.92	1.07	1.09	1.36	V	8 E
G.M.	1	2	2	16-13-16	16-14-16	0.81	1	0.87	1	V	8 E
B.E.	2.5	3	3	16-13-16	15-13-15	0.81	1	0.86	1	V	9 E

* Non–well-defined cases are italic and discordant cases are bold. The remaining cases are concordant.

not a valid instrument to calculate the speed of growth and skeletal maturation.[5,9] However, both sexual differences[5] and the great variation among subjects can be ascertained by a radiographic hand-wrist bone analysis with the Greulich and Pyle[1] atlas.

Moore[19] has pointed out that the facial bones differ from most of the skeleton because they are formed by intramembranous ossification with no cartilaginous precursor. Therefore, in comparison with general development, different factors are involved in each individual's facial growth.

In recent years, the modification of the cervical vertebrae in form and dimension has been reported, thus enabling the assessment of an individual's skeletal maturation rate.[10–17,19] The orthodontic clinical implications are interesting, and many authors have supported the efficacy of the cervical vertebral analysis to assess the skeletal age.[12–15,17]

The comparison between the hand-wrist bone analysis and the cervical vertebral analysis in our sample revealed a concordance in 25 individuals (83.3%). The Cohen κ index also revealed a good concordance (0.783). These same values were then confirmed in a second assessment on the same radiographs after 6 months. Given that in a Cohen κ statistical analysis even the unclassified cases are considered discordant, the differences between the first and the second evaluations do not change the results. Patient B.G. was CVMS I–II Bjork 4 (undefined) in the first evaluation and CVMS I Bjork 4 (discordant) in the second evaluation. Regarding skeletal aging, this shows that the significance of the cervical vertebral analysis, in particular CVMS and hand-wrist methods, is very close.

Our results confirm what was observed by San Roman et al,[20] but we think it is worth adding a consideration concerning both methods. Because growth is a continuous phenomenon, either the hand-wrist or the cervical vertebral indicators can present both non–well-defined patients and some whose growth is intermediate between two stages. As far as orthognathic purposes and from a clinical point of view, what matters is not a rigid stage classification but the identification of a growth interval.

TABLE 2. The Same Measurements and Intervals as in Table 1 After 6 Months (conc = concavity)

Patient	C2 conc (mm)	C3 conc (mm)	C4 conc (mm)	P3 B3 A3	P4 B4 A4	C3 BAR	C3 PAR	C4 BAR	C4 PAR	CVMS	Bjork
N.A.	1.5	0	0	11.5-15-7	11-15-8	2.14	1.64	1.87	1.37	I	1 A
S.M.	1	0	0	8-12.5-6	9.5-13-7	2.08	1.33	1.85	1.35	I	1 A
V.F.	0	0	0	10-12-8	10-13-8	1.5	1.25	1.62	1.25	I	1 A
V.O.	2	0	0	12-14-8	11.5-14-7	1.75	1.5	2	1.64	I	1 A
B.A.	0	0	0	10-14-6	10-15-7	2.33	1.66	2.14	1.42	I	2 A
M.M.	1	0	0	11-13-8	11-14-8	1.62	1.37	1.75	1.37	I	2 A
M.C.	1	0	0	11.5-16-8	12-15-9	2	1.43	1.66	1.33	I	3 A
G.M.	0	0	0	11-14-9	10-14-8	1.55	1.22	1.75	1.25	I	3 A
B.G.	**0**	**0**	**0**	**13-14-10**	**13-14-10**	**1.4**	**1.3**	**1.4**	**1.3**	**I**	**4 B**
M.A.	*1*	*1*	*0*	*10-14-7*	*9-15-7*	*2*	*1.42*	*2.14*	*1.28*	*II*	*3–4 A–B*
G.A.	1	1	0	13-15-9	11-16-9	1.66	1.44	1.77	1.22	II	4 B
M.S.	2	1	0	12-16-9	10-14-9	1.77	1.33	1.55	1.11	II	4 B
D.N.	1	1	0	10-13.5-8.5	10-13-10	1.58	1.17	1.3	1	II	4 B
T.T.	1	1	0	12-15-10	12-14-9	1.5	1.2	1.55	1.33	II	4 B
V.M.	2	1.5	0	11-15-9	11-15-9	1.66	1.22	1.66	1.22	II	4 B
T.A.	1	1.5	0	11-16-9	11.5-17-9	1.77	1.22	1.88	1.27	II	4 B
M.M.	1.5	2	1.5	14-15-12	14-15-10	1.25	1.16	1.5	1.4	III	5 C
T.S.	3	2	2	11-14-10	12-14-12	1.4	1.1	1.16	1	III	5 C
C.G.	1.5	2	1	13-14-10	11-15-9	1.4	1.3	1.66	1.22	III	5 C
M.A.	3	2	2	13-18-12	12-19-11	1.5	1.08	1.72	1.09	III	5 C
M.B.	1.5	2	1.5	13.5-13-12	13-13-11	1.08	1.12	1.18	1.18	III	5 C
G.C.	2	2	1	14-13-10	13-14-10	1.3	1.4	1.4	1.3	III	5 C
V.E.	1.5	1.5	2	13-15-10	12-15-10	1.5	1.3	1.5	1.2	III	5 C
M.E.	**2.5**	**2**	**2.5**	**14-15-14**	**14-15-13**	**1.07**	**1**	**1.15**	**1.07**	**III**	**9 E**
N.F.	2.5	3	2	14-14-14	14-14-13	1	1	1.07	1.07	IV	6 D
T.M.	*3*	*3*	*3*	*14-13-14*	*14-13-13*	*0.92*	*1*	*1*	*1.07*	*IV–V*	*8 E*
B.M.	**1.5**	**2**	**2**	**15-15-14**	**16-15-14**	**1.07**	**1.07**	**1.07**	**1.14**	**V**	**6 D**
B.E.	1.5	1	1.5	15-13-14	15-12-11	0.92	1.07	1.09	1.36	V	8 E
G.M.	2	2	2.5	17-14-17	16-15-16	0.82	1	0.93	1	V	8 E
B.E.	3	3	3	17-15-16	15-14-15	0.93	1.06	0.93	1	V	9 E

CONCLUSIONS

- The CVM method can be considered an efficient and repeatable procedure as confirmed by the evaluation carried out on the same radiographs after 6 months.
- The CVM method also presents the advantage of using the lateral cephalogram, which is a basic record for orthodontic diagnosis.

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