Original Article

Correlation of Skeletal Maturation Stages Determined by Cervical Vertebrae and Hand-wrist Evaluations

Carlos Flores-Mir[a]; Corr A. Burgess[b]; Mitchell Champney[c]; Robert J. Jensen[d]; Micheal R. Pitcher[e]; Paul W. Major[f]

Abstract: The aim of this study was to assess the correlation between the Fishman maturation prediction method (FMP) and the cervical vertebral maturation (CVM) method for skeletal maturation stage determination. Hand-wrist and lateral cephalograms from 79 subjects (52 females and 27 males) were used. Hand-wrist radiographs were analyzed using the FMP to determine skeletal maturation level (advanced, average, or delayed) and stage (relative position of the individual in the pubertal growth curve). Cervical vertebrae (C2, C3, and C4) outlines obtained from lateral cephalograms were analyzed using the CVM to determine skeletal maturation stage. Intraexaminer reliability (Intraclass correlation coefficient [ICC]) for both methods was calculated from 10 triplicate hand-wrist and lateral cephalograms from the same patients. An ICC coefficient of 0.985 for FMP and an ICC of 0.889 for CVM were obtained. A Spearman correlation value of 0.72 ($P < .001$) was found between the skeletal maturation stages of both methods. When the sample was subgrouped according to skeletal maturation level, the following correlation values were found: for early mature adolescents 0.73, for average mature adolescents 0.70, and for late mature adolescents 0.87. All these correlation values were statistically different from zero ($P < .024$). Correlation values between both skeletal maturation methods were moderately high. This may be high enough to use either of the methods indistinctively for research purposes but not for the assessment of individual patients. Skeletal level influences the correlation values and, therefore, it should be considered whenever possible. (*Angle Orthod* 2006;76:1–5.)

Key Words: Skeletal maturation; Cervical vertebrae; Growth prediction

INTRODUCTION

Optimal effectiveness in the use of orthodontic or orthopedic appliances has been associated with skeletal maturation. Functional appliances have been shown to be more effective when used in the peak of mandibular growth rather than earlier.[1,2] However, some authors have stated that because of the high variability in mandibular growth, this association may not be predictive enough for the individual patient.[3,4]

Skeletal maturation is generally determined by using ossification stages of bones of the hand and wrist because of the availability of different types of bones in the area.[5–9] There are two general approaches to the assessment of the hand-wrist radiograph. The first method consists of comparing the patient's hand-wrist bone maturation to an atlas.[7,9] The second method of assessment uses specific indicators to relate skeletal maturation to the pubertal growth curve. This approach focuses on the maturation evaluation of the individual rather than on mean values. Overall horizontal and vertical facial growth velocity has been shown to be related to skeletal maturity indicators determined by analysis of hand-wrist radiographs. Skeletal maturity analysis of hand-wrist radiographs for use in predicting facial growth velocity should include bone staging as well as ossification events.[10]

[a] Postdoctoral Fellow, Orthodontic Graduate Program, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, Canada.

[b] Undergraduate Student, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, Canada.

[c] Undergraduate Student, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, Canada.

[d] Undergraduate Student, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, Canada.

[e] Undergraduate Student, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, Canada.

[f] Professor, Director of the Orthodontic Graduate Program, Faculty of Medicine and Dentistry, University of Alberta, Edmonton, Alberta, Canada.

Corresponding author: Carlos Flores-Mir, DDS, CertOrth, PhD, Faculty of Medicine and Dentistry, Room 4051A, Dentistry/Pharmacy Centre, University of Alberta, Edmonton, Alberta, Canada T6G 2N8
(e-mail: carlosflores@ualberta.ca).

Accepted: March 2005. Submitted: February 2005.

Previous studies have shown that the progressive enlargement of cervical vertebrae bodies is related to human skeletal aging[11–13] and vertical facial patterns.[14,15] In recent years, evaluation of cervical vertebrae in lateral cephalograms has been increasingly used to determine the skeletal maturation.[16–19] The early version of the cervical vertebral maturation method (CVM) was shown to be a valid tool to predict the peak of mandibular growth[20,21] and was associated with mandibular morphological changes.[22] The CVM method, in the early or the improved version, has been used to evaluate the clinical effectiveness at different skeletal maturation stages of the Bionator,[2] RME,[23] Twin Block.[1]

Currently, the improved CVM method[24] is the most used cervical maturation evaluation method, whereas the Fishman maturation prediction method (FMP) seems to be the most appropriate method for skeletal maturation evaluation.[10] Although comparisons of skeletal maturation between different hand-wrist and cervical vertebrae indicators have already been made,[25–31] no direct comparison between FMP[32] (using both skeletal stage an skeletal level) and the improved CVM method[24] were found in the literature.

A distinctive advantage of the cervical maturity evaluation is that it does not imply extra radiation exposure for the patient. If hand-wrist and cervical maturation methods were highly correlated, there would be no justification to take an extra hand-wrist radiograph for skeletal maturation determination. The objective of this study was to assess the correlation between FMP and CVM methods for the determination of skeletal maturation stage.

MATERIALS AND METHODS

Sample characteristics

This sample was previously used to evaluate longitudinal craniofacial morphology changes associated with temporomandibular joint (TMJ) disk status.[33] Only 79 subjects (52 females and 27 males) had hand-wrist radiographs and lateral cephalogram of adequate quality.

Variables

Hand-wrist radiographs were analyzed using the FMP[32] to determine skeletal maturation level (advanced, average, or delayed) and stage (relative position of the individual in the pubertal growth curve). The hand-wrist radiographs were scanned at 300 dpi and sent through e-mail to GrowthTek.[34] The appropriate skeletal maturation stage and level was determined independently by a calibrated technician at the Growth Tek Company (Skaneateles, NY) according to the FMP. Previously, it was determined that under these conditions, scanned hand-wrist radiographs would be adequate for the evaluation purposes. Complete details about FMP can be found elsewhere.[32,34]

Closed-mouth lateral cephalometric radiographs were obtained for each subject with a Siemens OP 10 (Siemens, Bensheim, Germany) machine, with the mandible stabilized by a polyvinylsiloxane habitual occlusion bite registration. Outlines of the cervical vertebrae (C2, C3, and C4) were evaluated by CF and the appropriate skeletal maturation stage was determined according to CVM. Complete details of the CVM can be found elsewhere.[24]

Efforts were made to make the research process as blind as possible. The evaluators who completed maturation prediction using CVM were blinded to the skeletal maturation stage determined by FMP and vice versa. A statistician completed the statistical analysis without specific knowledge of the coding of the maturational stages.

Statistical analysis

A one-way random intraclass correlation coefficient (ICC) was used to determine the reliability of the diagnosis for the FMP and the CVM. Assumptions of normality were not fulfilled. Therefore, a nonparametric Spearman correlation test was used to correlate the skeletal maturation stage between both methods. The correlation was also evaluated by grouping the subjects according to their skeletal maturation level.

RESULTS

Error of method

Intraexaminer reliability (ICC) for both methods was calculated from 10 triplicate hand-wrist and lateral cephalograms from the same patients. An ICC coefficient of 0.985 (0.959 to 0.996; $P < .001$) was obtained for FMP and an ICC of 0.889 (0.723 to 0.968; $P < .001$) was obtained for CVM.

Skeletal maturation stages

The distribution of the skeletal maturation stages for the sample according to FMP and CVM are shown in Tables 1 and 2.

Correlation values

A Spearman correlation value of 0.72 was found between the skeletal maturation stages of both methods.

When the skeletal maturation level according to FMP was considered, the following correlation values were found: for early mature adolescents 0.73, for average mature adolescents 0.70, and for late mature

TABLE 1. Frequency of Individuals in Each Category According to FMP[a]

Skeletal Maturation Stage	Individuals	Percentage
1	10	12.7
2	1	1.3
3	4	5.1
4	10	12.7
5	4	5.1
6	8	10.1
7	11	13.9
8	8	10.1
9	9	11.4
10	14	17.7
11	6	7.6
Total	79	100.0

[a] FMP indicates Fishman maturation prediction method.

TABLE 2. Frequency of Individuals in Each Category According to CVM[a]

Skeletal Maturation Stage	Individuals	Percentage
1	19	24.1
2	17	21.5
3	11	13.9
4	25	31.6
5	7	8.9
Total	79	100.0

[a] CVM indicates Cervical Vertebral Maturation.

TABLE 3. Spearman's Correlation Between the FMP and the CVM According to Skeletal Maturation Level

	Number of School Children	*R* of Spearman	Significance (*P* Value)
Advanced	16	0.725	.001
Average	57	0.698	$<$.001
Delayed	6	0.871	.024

adolescents 0.87. All the values were statistically different from zero ($P < .024$), as shown in Table 3.

DISCUSSION

Because chronological age is not a valid predictor of skeletal growth velocity or skeletal maturity,[8,35–37] conventionally, hand-wrist radiographs have been used to determine skeletal maturation. Validity of skeletal maturity assessment using the hand-wrist radiograph in relation to the standing height (body skeletal growth velocity) has been well established for several racial groups.[37–40] Although Moore[41] pointed out that most of the bones of the body are preformed in cartilage and later developed by endochondral ossification, the facial bones are formed by intramembranous ossification without cartilaginous precursors. Therefore, growth of the face may be regulated by factors other than those responsible for growth of the long bones. Furthermore, the craniofacial structures include several functional regions that may have different growth responses to systemic and local environmental conditions.

Recently, the use of cervical vertebrae maturation has been suggested as a valid replacement to the hand-wrist evaluation. The main advantage of the cervical vertebrae maturation evaluation is that it can be obtained from a conventional lateral cephalogram, which would avoid an extra radiation exposure for the patients.

The results of this study suggested that although the correlation values between both methods were high (0.72), they could only predict around 50% of the other method's skeletal maturation determination. Previous research found that correlation values between skeletal maturation determined from hand-wrist radiographs and cervical vertebrae evaluation were quite variable (from 0.45 to 0.97) (Table 4). Differences between the results of this study and the reported comparison studies can be expected on the basis of the

TABLE 4. Correlation Values Between the Skeletal Maturation Determined From Hand-wrist Radiographs and Cervical Vertebrae Evaluation From the Lateral Cephalometric Radiographs

	Number of Subjects (Males/Females)	Total *R* (*R* Males/*R* Females)	Hand-wrist Skeletal Maturation Method
Caltabiano et al[30]	72 (27/45)	NS (0.450/0.564)	Fishman's SMI[32]
Chang et al[31]	503 (244/259)	NS (0.973/0.970)	Fishman's SMI[32]
Garcia-Fernandez et al[26]	113 (50/63)	NS (NS/NS)[a]	Fishman's SMI[32]
Kucukkeles et al[27]	180 (99/81)	NS (NS/NS)[b]	Fishman's SMI[32]
Mito et al[28]	66 (0/66)	NS (NA/0.869)	TW2[9]
San Roman et al[29]	958 (428/530)	NS (0.69, 0.77, 0.79/0.79, 0.84, 0.85)	Grave and Brown[39]
Zhang and Wang[25]	70 (28/42)	NS (NS/NS)	Presence of sesamoid

[a] Wilcoxon matched-pairs signed-ranks tests.
[b] Agreement formula.
NS Not significant

factors such as sample size, sex, or specific methods used.

The size of the sample used in this study is comparatively small but presents a distinctive advantage in that it analyzes for the first time the influence of skeletal level (advanced, average, or delayed maturation). Because the use of individual ossification events is of limited use in predicting the pubertal growth spurt, an analysis that includes maturation levels as well as ossification events is recommended.[10] Consideration of maturation level is significantly important for treatment timing. For example, during late adolescence, advanced maturers express significantly less growth velocity and incremental growth as compared with average and especially delayed maturers who continue growth for a longer period until adulthood. During the accelerating and high velocity periods of adolescence, advanced maturers express significantly higher growth rates and express more growth over shorter time periods. Therefore, the importance of establishing the maturational age of an individual is to predict the remaining growth. Orthodontic or surgical (or both) treatment success depends on understanding this.[42] Therefore, analysis approaches such as the one described by Fishman,[32,34] which are based on relative growth velocity and percentage of growth remaining, are more useful than analyses which yield a ''skeletal age.'' Avoidance of a skeletal age minimizes the influence of environment and racial composition of the sample. In most cases, use of relative growth rate and percentage of growth remaining will resolve sex differences.

The results of this study showed that skeletal level has an influence on the amount of correlation between skeletal maturation determined by different methods. Therefore, future studies about skeletal maturation should take this factor into consideration. A larger sample size may be required to confirm the findings of this study because the delayed matured group only had six individuals in the present sample.

Although the use of FMP has distinct advantages[10] over the other skeletal maturation determination methods, current stringent ethical criteria from the institutional ethical boards make the use of hand-wrist skeletal maturation determination less feasible. Increased radiation exposure is the main reason. Also, in some retrospective research endeavors, the lack of hand-wrist radiographs may also limit the applicability of existing data. Therefore, the use of cervical vertebrae maturation determination appears to be a useful tool in situations where there are no hand-wrist radiographs available.

Even if in a clinical situation, an individual skeletal maturation determination may be possible. Some authors have stated that because of the high variability in mandibular growth, this association may not be predictive enough for the individual patient.[3,4] Therefore, assessment of skeletal maturation may be valuable as an orthodontic research tool (group not individual subject's skeletal maturation), but it has limited predictive use in the individual patient. Realizing the limitations of either method for clinical practice, the reduced radiation resulting from avoidance of an additional radiograph may justify the use of cervical maturation.

CONCLUSIONS

- Correlation values between FMP and CVM were moderately high.
- Skeletal level influences the correlation values and should be considered whenever possible.

REFERENCES

1. Baccetti T, Franchi L, Toth LR, McNamara JA Jr. Treatment timing for Twin-block therapy. *Am J Orthod Dentofacial Orthop.* 2000;118:159–170.
2. Faltin KJ, Faltin RM, Baccetti T, Franchi L, Ghiozzi B, McNamara JA Jr. Long-term effectiveness and treatment timing for Bionator therapy. *Angle Orthod.* 2003;73:221–230.
3. Mitani H, Sato K. Comparison of mandibular growth with other variables during puberty. *Angle Orthod.* 1992;62:217–222.
4. Sato K. Growth timing of mandibular length, body height, hand bones and cervical vertebrae during puberty. *Nippon Kyosei Shika Gakkai Zasshi.* 1987;46:517–533.
5. Bambha J, van Natta M. Longitudinal study of facial growth in relation to skeletal maturation during adolescence. *Am J Orthod.* 1963;39:481–493.
6. Bjork A, Helm S. Prediction of the age of maximum pubertal growth in body height. *Angle Orthod.* 1967;37:134–143.
7. Greulich W, Pyle S. *Radiographic Atlas of Skeletal Development of Hand and Wrist.* Stanford, Calif: Stanford University Press; 1959.
8. Houston WJ, Miller JC, Tanner JM. Prediction of the timing of the adolescent growth spurt from ossification events in hand-wrist films. *Br J Orthod.* 1979;6:145–152.
9. Tanner JM, Whitehouse RH, Cameron N, Marshall WA, Healy MJR, Goldstein H. *Assessment of Skeletal Maturity and Prediction of Adult Height (TW2 Method).* London, UK: Academic Press; 1983.
10. Flores-Mir C, Nebbe B, Major PW. Use of skeletal maturation based on hand-wrist radiographic analysis as a predictor of facial growth: a systematic review. *Angle Orthod.* 2004;74:118–124.
11. Israel H. Progressive enlargement of the vertebral body as part of the process of human skeletal ageing. *Age Ageing.* 1973;2:71–79.
12. Hellsing E. Cervical vertebral dimensions in 8-, 11-, and 15-year-old children. *Acta Odontol Scand.* 1991;49:207–213.
13. Taylor JR. Growth of human intervertebral discs and vertebral bodies. *J Anat.* 1975;49:49–68.
14. Karlsen AT. Association between vertical development of the cervical spine and the face in subjects with varying vertical facial patterns. *Am J Orthod Dentofacial Orthop.* 2004;125:597–606.
15. Salagnac JM, Delaire J, Mercier J. Vertical development of the face and cervical spine. Diagnostic and therapeutic sig-

nificance in orthodontics and maxillofacial surgery. *Rev Stomatol Chir Maxillofac.* 1999;100:13–26.
16. Hassel B, Farman AG. Skeletal maturation evaluation using cervical vertebrae. *Am J Orthod Dentofacial Orthop.* 1995; 107:58–66.
17. Mito T, Sato K, Mitani H. Predicting mandibular growth potential with cervical vertebral bone age. *Am J Orthod Dentofacial Orthop.* 2003;125:173–177.
18. Franchi L, Baccetti T, McNamara JA Jr. Treatment and posttreatment effects of acrylic splint Herbst appliance therapy. *Am J Orthod Dentofacial Orthop.* 1999;115:429–438.
19. Lamparski D. *Skeletal Age Assessment Utilizing Cervical Vertebrae.* [master's thesis]. Pittsburgh, Pa: University of Pittsburgh; 1972.
20. Franchi L, Baccetti T, McNamara JA Jr. Mandibular growth as related to cervical vertebral maturation and body height. *Am J Orthod Dentofacial Orthop.* 2000;118:335–340.
21. O'Reilly MT, Yanniello GJ. Mandibular growth changes and maturation of cervical vertebrae—a longitudinal cephalometric study. *Angle Orthod.* 1988;58:179–184.
22. Franchi L, Baccetti T, McNamara JA Jr. Thin-plate spline analysis of mandibular growth. *Angle Orthod.* 2001;71:83–89.
23. Baccetti T, Franchi L, Cameron CG, McNamara JA Jr. Treatment timing for rapid maxillary expansion. *Angle Orthod.* 2001;71:343–350.
24. Baccetti T, Franchi L, McNamara JA Jr. An improved version of the cervical vertebral maturation (CVM) method for the assessment of mandibular growth. *Angle Orthod.* 2002; 72:316–323.
25. Zhang Y, Wang B. Observation of cervical vertebrae and estimation of their bone age. *Chung Hua Kou Chiang Hsueh Tsa Chih.* 1997;32:152–154.
26. Garcia-Fernandez P, Torre H, Flores L, Rea J. The cervical vertebrae as maturational indicators. *J Clin Orthod.* 1998; 32:221–225.
27. Kucukkeles N, Acar A, Biren S, Arun T. Comparisons between cervical vertebrae and hand-wrist maturation for the assessment of skeletal maturity. *J Clin Pediatr Dent.* 1999; 24:47–52.
28. Mito T, Sato K, Mitani H. Cervical vertebral bone age in girls. *Am J Orthod Dentofacial Orthop.* 2002;122:380–385.
29. San Roman P, Palma JC, Oteo MD, Nevado E. Skeletal maturation determined by cervical vertebrae development. *Eur J Orthod.* 2002;24:303–311.
30. Caltabiano M, Leonardi R, Zaborra G. Evaluation of cervical vertebrae for determination of skeletal age. *Riv Ital Odontoiatr Infant.* 1990;1:15–20.
31. Chang HP, Liao CH, Yang YH, Chang HF, Chen KC. Correlation of cervical vertebra maturation with hand-wrist maturation in children. *Kaohsiung J Med Sci.* 2001;17:29–35.
32. Fishman L. Maturational development and facial form relative to treatment timing. In: Subtenly J, ed. *Early Orthodontic Treatment.* Chicago, Ill: Quintessence Publishing; 2000: 265–285.
33. Flores-Mir C, Nebbe B, Heo G, Major PW. Longitudinal study on TMJ disk status and craniofacial growth. *Am J Orthod Dentofacial Orthop.* In press.
34. GrowthTek. Available at: www.growthtek.com. Accessed February 10, 2005.
35. Bowden BD. Epiphysial changes in the hand/wrist area as indicators of adolescent stage. *Aust Orthod J.* 1976;4:87–104.
36. Fishman LS. Chronological versus skeletal age, an evaluation of craniofacial growth. *Angle Orthod.* 1979;49:181–189.
37. Hägg U, Taranger J. Maturation indicators and the pubertal growth spurt. *Am J Orthod.* 1982;82:299–309.
38. Nanda R. The rates of growth of several facial components measured from serial cephalometric roentnograms. *Am J Orthod.* 1955;41:658–673.
39. Grave KC, Brown T. Skeletal ossification and the adolescent growth spurt. *Am J Orthod.* 1976;69:611–619.
40. So LL. Correlation of sexual maturation with skeletal age of southern Chinese girls. *Aust Orthod J.* 1997;14:215–217.
41. Moore RN. Principles of dentofacial orthopedics. *Semin Orthod.* 1997;3:212–221.
42. Fishman LS. Can cephalometric x-rays of the cervical column be used instead of hand-wrist x-rays to determine a patient's maturational age? *Am J Orthod Dentofacial Orthop.* 2002;122:18A–19A.