

Original article

# The cervical vertebrae maturation (CVM) method cannot predict craniofacial growth in girls with Class II malocclusion

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## Summary

**Introduction:** The cervical vertebrae maturation (CVM) method is used to determine the timing of treatment of Class II malocclusion. Because its performance has not been tested in patients with Class II, the objective of this study was to evaluate the effectiveness of the CVM method in predicting craniofacial growth in Class II malocclusion.

**Methods:** Twenty-nine untreated girls with Class II malocclusion were identified among participants of the Nijmegen Growth Study. Each girl had a series of cephalograms taken semi-annually from 9 to 14 years of age. The CVM status was established by five observers on a cephalogram taken at 9 years; mandibular and maxillary length and anterior face height were assessed on all available cephalograms. Method error was evaluated with kappa statistics and Bland–Altman (BA) plots. Regression analysis was used to determine if CVM grade can predict the amount of facial growth.

**Results:** The mean kappa for intra-rater agreement during grading with CVM was 0.36 (fair agreement). BA plots demonstrated acceptable agreement for cephalometric measurements. The regression analysis demonstrated that the only chronologic age was associated with the facial growth. The largest effect of age was for condylion–gnathion (Cd–Gn) and articulare–gnathion (Ar–Gn)—for every additional 6 months the Cd–Gn increases by 1.8 mm [95 per cent confidence interval (CI): 1.7, 1.9,  $P < 0.001$ ] and Ar–Gn increases by 1.59 mm (95 per cent CI: 1.52, 1.67,  $P < 0.001$ ). The CVM grade could not predict the change of cephalometric variables.

**Conclusions:** There is no evidence to support the hypothesis that the CVM method can predict the amount of craniofacial growth in girls with Class II malocclusion.

## Introduction

The timing of orthodontic therapy may influence the final outcome. For example, skeletal Class II division 1 malocclusion is frequently associated with hypoplastic mandible, retruded chin (1) and, consequently, unaesthetic facial profile. Evidence from a systematic review (2) suggests that initiation of orthodontic Class II correction before the pubertal growth spurt results mainly in dento-alveolar changes

with little alterations of the facial skeleton. This scenario is not optimal because the underlying skeletal problem is not actually corrected and the facial profile may not sufficiently improve. Some evidence (3–5) implies, however, that deferring treatment with functional appliances until the commencement of the growth spurt may result in a more favourable skeletal correction.

A practical problem associated with timing of the therapy is the identification of a period of maximum growth. Two popular

methods have been used and are still in use to this end in orthodontics: 1. assessment of hand-wrist (HW) radiographs and 2. evaluation of cervical vertebrae maturation (CVM). In the HW method, skeletal maturation is determined on the basis of the stages of ossification of the bones of the hand and the wrist (6, 7), whereas changes in the cervical vertebrae morphology are used in the CVM method (8–10). Both methods relate maturational stages in the corresponding areas with general and facial growth. The CVM method does not require an additional radiograph for assessment and for this reason it has been widely used by clinicians worldwide.

A method can be implemented for diagnostic purposes if it is valid and reproducible. Validity refers to accuracy of the method, i.e. how well the method measures what it purports to measure. To be reproducible a measurement should be the same if repeated by the same or different observer (11). Several early studies showed excellent reproducibility of the CVM method (4, 9, 10, 12–14); however, those early findings have been questioned and even refuted in more recent studies (15–17). The primary reason for criticism was that in those studies the assessment of reliability of the CVM method was under ideal conditions which are unattainable in every day clinical practice. A number of studies have shown, however, that the reliability of the method can differ when under ideal conditions and when used in everyday practice (18, 19). A recent study by Beit *et al.* (20) concluded that ‘... assessment of age-dependent changes in the cervical spine offers no advantage over chronologic age, in either assessing skeletal age or predicting the pubertal growth spurt’.

Additionally, it has been suggested that the CVM method can predict the pubertal growth peak in Class II malocclusion (10). None of the previous studies (9, 10, 12, 13) have tested the validity of the CVM method in predicting the pubertal growth peak in Class II patients. It was therefore, the aim of this study to evaluate the performance of the CVM method in predicting craniofacial growth in subjects with Class II malocclusion.

## Subjects and methods

### Subjects

Subjects for this investigation were selected from the Nijmegen Growth Study (NGS). The NGS was a mixed-longitudinal, interdisciplinary study of the growth and development of 486 normal Dutch children (232 boys and 254 girls). During the study six cohorts of children born between 1961 and 1967 were measured every 3 months. The repeated measurements were taken during the 5 years, 1970–75, covering a total age range of 4–14 years, with some overlapping of the ages over which the various cohorts were followed. During each examination period numerous measurements were taken including anamnestic variables (i.e. changes in medical history), dental variables (cephalograms and dental casts), medical variables (e.g. blood tests, HW X-rays), psychological variables (e.g. intelligence tests), and anthropometric variables (e.g. evaluations of stature height, body weight, and leg length). Cephalometric radiographs and dental study casts were made twice a year in each subject (21).

The NGS was terminated when participants turned 14 years of age. At this age most boys were likely still be in the growth spurt stage and we decided to exclude them from the study. In contrast, many girls had likely completed or were close to completion of pubertal growth spurt by the age of 14. In order to include a more homogenous sample we decided to select from the NGS database only female participants who had a complete series of

cephalograms taken semi-annually from 9 until 14 years of age. Subsequently their dental casts were inspected to identify those girls with Angle Class II malocclusion. For the purpose of this study only girls with at least ½-cusp Class II on both right and left sides were considered. Exclusion criteria were: orthodontic treatment during the period of observation, visible pathology of cervical vertebrae, and poor representation of second, third, or fourth cervical vertebrae (C2, C3, C4).

### Methods

Cephalograms taken at 9 years of age were used to establish a CVM status according to the method proposed by Baccetti *et al.* (10). The radiographs were scanned at 300 dpi resolution. Then the images were cropped to restrict visualization to the cervical vertebrae; thus, the dentition was not visible on any of the images. Subsequently, the scans were loaded into PowerPoint to prepare a presentation for the CVM rating. A PowerPoint presentation consisted of a detailed description of the CVM method along with instructions on how to rate, examples of all stages of skeletal maturity, and all images to be assessed. The presentation file was sent to five raters (senior orthodontic residents). Prior to rating a calibration session took place during which observers rated 20 other cephalograms and discussed their scores. Raters assessed cephalograms at the time of convenience but not later than 1 day after the calibration session. There was no time restriction on the length of rating session, i.e. each rater used as much time as he/she needed for assessment. The raters reassessed cephalograms after at least 4 weeks. The order of images was randomly changed in the second rating session. The raters did not participate in the design or construction of the research project.

The following measurements were performed on each semi-annual cephalogram: condyilion–point A (Cd–A), condyilion–gnathion (Cd–Gn), articulare–point A (Ar–A), articulare–gnathion (Ar–Gn), nasion–anterior nasal spine (N–Spa), and anterior nasal spine–menton (Spa–Me)—Figure 1. The measurements were completed independently by two calibrated investigators using the Onyx CEPH 3™ version 3.1.36 (52) software (Image Instruments GmbH, Chemnitz, Germany). The images were adjusted for magnification. Both investigators remeasured 30 randomly selected cephalograms after a minimum 4 weeks.

### Statistical analysis

Intra- and inter-observer reliability of scoring with the CVM method was evaluated with kappa statistics. For intra-observer agreement individual kappas were calculated. For inter-rater agreement the mean kappa for 10 pairs of observers (O1 versus O2, O1 versus O3, etc.) was calculated. The interpretation of kappa was as follows (22): kappa values from 0.01 to 0.20 indicate slight agreement, from 0.21 to 0.40—fair agreement, from 0.41 to 0.60—moderate agreement, from 0.61 to 0.80—very good, and from 0.81 to 1—almost perfect agreement.

Moreover the Bland–Altman (BA) limits of agreements were carried out in order to assess intra-observer and inter-observer agreement during cephalometric measurements (22).

A linear mixed model was fitted in order to determine potential associations between the individual measurements (Cd–A, Cd–Gn, Ar–A, Ar–Gn, N–Spa, and Spa–Me—dependent variables) and average across observers CVM scoring after adjusting for age and accounting for the within patient correlations. All analyses were conducted using the Stata 13.1 statistical package (Stata Corp, College Station, Texas, USA).

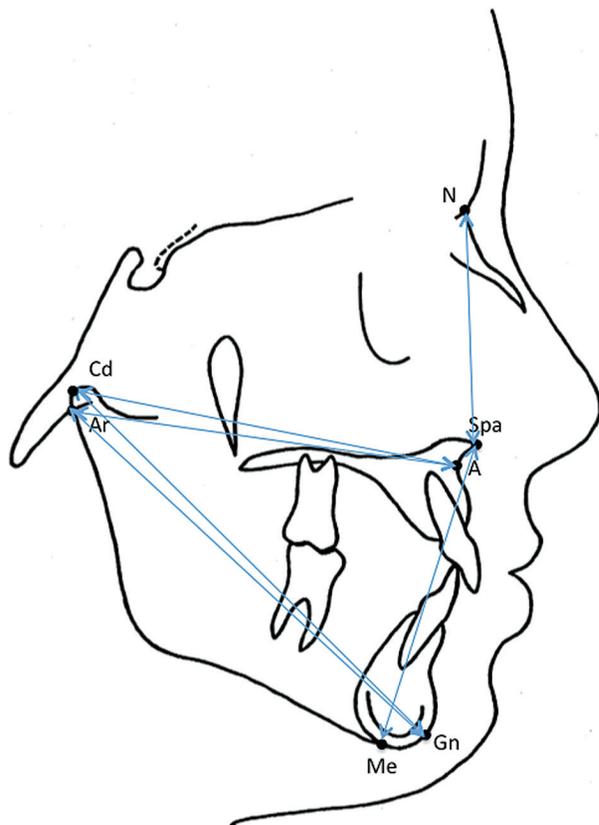


Figure 1. Cephalometric measurements.

## Results

Thirty-nine girls (15.4 per cent) of the 254 females participating in the NGS had bilateral Angle Class II. Twenty-nine of them (74.4 per cent) were not treated orthodontically until the age of 14 years, i.e. until the end of the NGS. All participants had good quality cephalograms with a full representation of cervical vertebrae from C2 to C4 and were included in the study (Figure 2). The total number of assessed cephalograms was 302 and all cephalograms were of comparable quality with good representation of facial skeleton. The subjects were born between August and December 1961. They were 9.3 years old (SD = 0.2) at the start of this study. Five girls had bilateral full cusp Class II, 5 had full cusp Class II on one side and ½ cusp on the other side, and 18 girls had ½ cusp Class II on both sides. Two girls had lateral crossbite, 11 girls had deep bite, and 1 girl had anterior open bite.

At 9.3 years of age, the mean CVM grade for all five observers and two rating sessions was 2.4 (SD = 1.4). In 5 subjects the mean CVM grade was 1.5 or below, in 8 subjects—between 1.6 and 1.9, in 4 subjects—between 2.0 and 2.4, in 7—between 2.5 and 2.9, in 5—between 3 and 3.4, and in 2 was 3.5 or more.

The mean kappa for intra-rater agreement in assignment of CVM status was 0.36 (fair agreement). The individual kappas ranged from 0.18 (rater 1, slight agreement) to 0.54 (rater 5, moderate agreement). Lower limits of 95 per cent confidence interval (CI) ranged from 0.03 (rater 1) to 0.43 (rater 3)—Table 1. The mean kappa for all pairs of raters (inter-rater agreement) was 0.30 (95% CI: 0.27, 0.35), which indicates fair agreement—Table 1. BA plots demonstrated acceptable intra- and inter-observer agreement (Figure 3a and 3b).

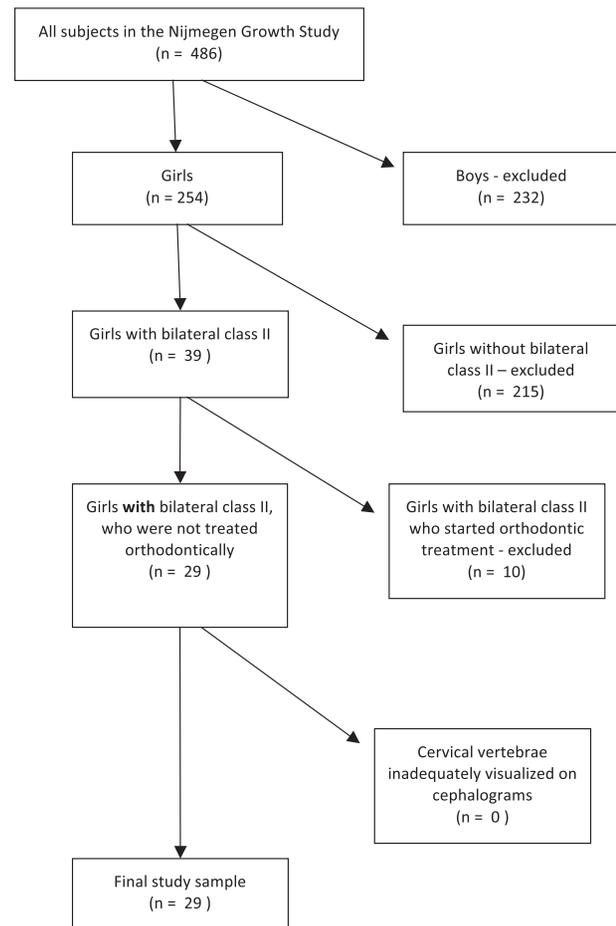


Figure 2. Flow diagram presenting sample selection process.

Table 1. Intra- and inter-rater agreement during assignment of the CVM grade.

Intra-rater			
Rater	Kappa	95% CI	P value
1	0.18	0.03–0.41	0.086
2	0.38	0.19–0.52	0.000
3	0.46	0.43–0.54	0.000
4	0.26	0.04–0.37	0.004
5	0.54	0.34–0.63	0.000
Inter-rater			
Combined	0.30	0.27–0.35	0.000

CI, confidence interval; CVM, cervical vertebrae maturation.

The age range in which girls showed a maximum growth of the mandible is presented in Figure 4. The changes of cephalometric variables are presented in Table 2. The regression analysis demonstrated that the only parameter associated with the change of cephalometric variables, i.e. facial growth, was chronologic age (Table 3). The largest effect of age was for Cd–Gn and Ar–Gn variables—for every additional 6 months of age the Cd–Gn measurement increases by 1.8 mm (95 per cent CI: 1.7, 1.9,  $P < 0.001$ ) and the Ar–Gn measurement increases by 1.59 mm (95 per cent CI: 1.52, 1.67,  $P < 0.001$ ). The smallest effect of age was for N–Spa—for every additional 6 months of age the N–Spa increases by 0.8 mm (95 per cent CI:

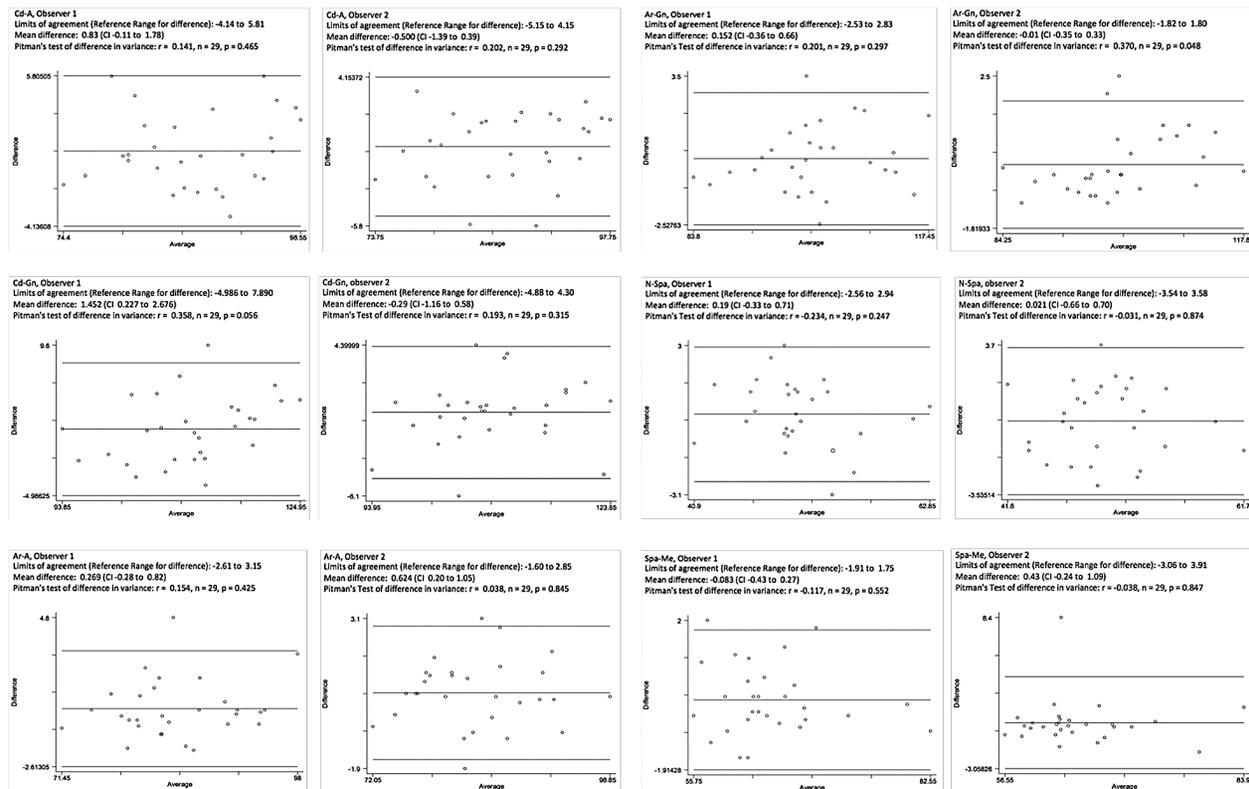


Figure 3. Bland-Altman plots demonstrating the bias for cephalometric variables.

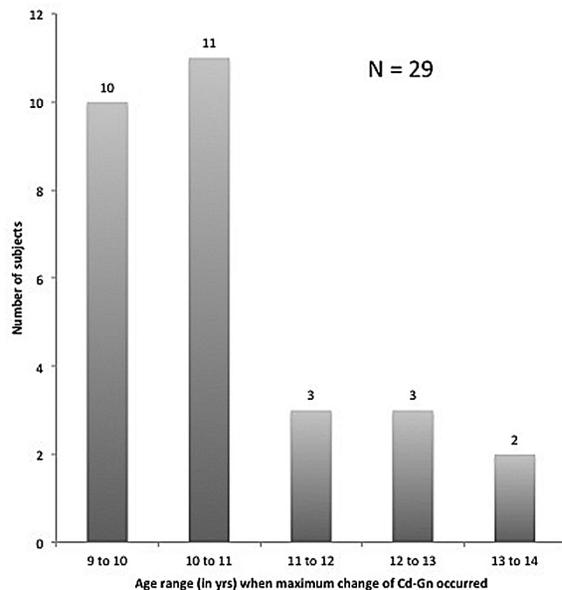


Figure 4. The age range (in years) when a maximum growth of the mandible (condyion to gnathion) occurred.

0.73, 0.87,  $P < 0.001$ ). The CVM grade was not a significant predictor of change of cephalometric variables after adjusting for age.

## Discussion

The CVM method has been used in orthodontics to predict the time of when the maximum rate of facial growth occurs and particularly

in patients with Class II malocclusion and hypoplastic mandible. It is widely assumed that when a goal of treatment of Class II is to maximize mandibular prominence, it should be initiated during the growth spurt, ideally just before the peak of growth. It is hypothesized that if treatment is completed either too early or too late relative to the time of maximum facial growth, little change in mandibular prominence could be obtained.

The validity of CVM method for assessment of facial growth has been tested with two gold standards: 1. skeletal age obtained with the HW staging (8,12,23) or 2. directly related with changes of cephalometric variables (10, 24, 25). Many studies using the HW staging as the gold standard have shown a high correlation between the CVM and HW statuses (26). However, it is unclear if changes in the HW staging reflect precisely facial growth—some reports suggest a close association between postural and facial growth (27,28), whereas other studies imply a weak association between them (29,30). The validation of the CVM with cephalometric analysis of facial growth has shown a statistically significant but clinically questionable association between the CVM grade and facial growth (17).

Our main finding is that the CVM grade is not associated with facial growth; therefore its use for prediction of facial growth in patients with Class II malocclusion seems questionable. Our results agree with reports of Gabriel *et al.* (15), Ball *et al.* (31), Nestman *et al.* (16), and Zhao *et al.* (17). The studies by Gabriel *et al.*, Nestman *et al.*, and Zhao *et al.* pointed out to relatively high percentage of disagreement between raters as a cause for reduced reliability of the CVM method. Nestman *et al.* stated that difficulty in classifying the vertebral bodies of C3 and C4 as trapezoidal, rectangular horizontal, square, or rectangular vertical was a serious weakness of the CVM method. This difficulty led to the overall poor reproducibility of the CVM method and lack of its adoption as a strict clinical guideline



**Table 3.** Regression models with average CVM grade of all raters and age of the subject as independent variables and change of cephalometric variable as dependent variable.

	$\beta$	95% CI	P value
Cd-A			
CVM grade—average for all raters	-0.05	-1.80 to 1.70	0.95
Age	1.23	1.15 to 1.32	<0.001
Cd-Gn			
CVM grade—average for all raters	-1.19	-3.14 to 0.76	0.23
Age	1.8	1.71 to 1.90	<0.001
Ar-A			
CVM grade—average for all raters	0.39	-1.26 to 2.03	0.65
Age	1.05	0.99 to 1.11	<0.001
Ar-Gn			
CVM grade—average for all raters	-0.76	-2.68 to 1.15	0.44
Age	1.59	1.52 to 1.67	<0.001
Spa-Me			
CVM grade—average for all raters	1.28	-0.76 to 3.33	0.22
Age	0.87	0.81 to 0.93	<0.001
N-Spa			
CVM grade—average for all raters	-1.27	-2.76 to 0.21	0.92
Age	0.8	0.73 to 0.87	<0.001

Ar-A, articulare–point A; Ar-Gn, articulare–gnathion; Cd-A, condylion–point A; Cd-Gn, condylion–gnathion; CI, confidence interval; CVM, cervical vertebrae maturation; N-Spa, nasion–anterior nasal spine; SD, standard deviation; Spa-Me, anterior nasal spine–menton.

for the timing of orthodontic treatment. In addition, Zhao *et al.* found that the percentage of complete agreement between observers for assignment of CVM stage 3, i.e. the stage, which is supposed to precede the maximum facial growth, was only 26.8 per cent. A disagreement of one stage apart was found in 49.5 per cent, two stages apart—in 22.2 per cent, and three stages apart in 1.5 per cent scorings. From a clinical point of view, disagreement by one CVM stage roughly corresponds with a 1-year difference in predicted maximum facial growth (8). Because a typical treatment of Class II with functional appliance lasts 1 year, inaccuracy of the CVM method may be unacceptable.

In contrast to previous reports, Ball *et al.* (31) found almost perfect concordance among raters using the CVM system. Nevertheless the authors stated that the CVM was unable to predict the onset of a peak in mandibular growth because of the duration of particular CVM stages. According to Baccetti *et al.* (10) the peak in mandibular growth occurs between third and fourth CVM stage and the stages last approximately 1 year. Therefore if a subject has CVM stage 3, the maximum facial growth should occur within 12 months. Ball *et al.* reported, in turn, that the peak of mandibular growth in their sample occurred in fourth CVM stage and the duration of this stage was on average 3.8 years. As a result identification of the CVM stage 4 in a patient gives time span that is too wide to accurately predict the peak of growth.

Several studies demonstrated a high association between the CVM stage and facial growth (9, 10, 25, 32). Our results are in conflict with them. There are several possible explanations for this. First, it is unclear if researchers performing cephalometric analysis were blinded to the results of CVM staging, and *vice-versa*. It is particularly important when a team of researchers works on the same records for extended period of time. A developing ‘memory effect’ can introduce bias into the results. Secondly, in the current study we applied a strategy that mimicks a typical clinical situation, when the orthodontist after evaluation of a cephalogram attempts to predict facial growth. O’Reilly and Yanniello (25), Franchi *et al.* (9), and Baccetti *et al.* (10, 32) used a different approach—they identified the period of greatest change of cephalometric variable(s) and correlated

it with morphology of cervical vertebrae C2, C3, and C4. These two strategies, although seem complementary, they may look at different aspects of facial growth and for this reason may produce conflicting findings. Finally, missing (25) or incomplete (9, 10, 32) method error analysis makes the assessment of accuracy of cephalometric measurements difficult.

The consistency of CVM staging was relatively low in this investigation. The intra- and inter-rater agreement was worse than in most other publications. It can result from the composition of the rater’s panel—we asked senior orthodontic residents to stage CVM status whereas other authors performed CVM staging themselves (9, 10, 12–14). Although our raters were calibrated, their experience in using the CVM system might have been less than that of raters from other studies. On the other hand, the use of a panel comprising residents rather than highly trained experts may resemble better the everyday clinical practice situation.

The use of CVM requires that second, third, and fourth cervical vertebrae are visible on a cephalogram. As a result, if this region of cervical spine is to be visualized no thyroid shield can be worn during radiographic exposition. However, the thyroid gland is one of the most radiation-sensitive parts of the body. External irradiation to the thyroid, even at low doses, may induce subsequent development of nodules and neoplasmas and is associated with an increased incidence of thyroid autoimmune abnormalities and the development of thyroiditis and Graves’ disease (33). Since the use of thyroid shield can considerably reduce the effective dose of the thyroid (34) taking lateral cephalograms without thyroid shield is questionable because of an increased health hazard and a little benefit for a patient.

The participants included in our study were followed until 14 years of age. Ideally a series of examinations should be finished at 17–18 years when the pubertal phase of facial growth is expected to be completed. This was not possible because the NGS had been planned to cover only the years from 4 to 14. However, our aim was to test the performance of the CVM method to predict the peak of facial growth, which very likely occurred within the age range of our participants (35). Buschang *et al.* using a large French–Canadian sample of girls born in 1960s demonstrated that peak growth

velocities were well before 13 years of age. Thus the sample seems appropriate for this study.

A limitation of our study could be a relatively small sample size. Increasing the number of subjects in the sample would increase the power to detect smaller growth increments; however, any uncertainty in our estimates is reflected in the provided CIs.

In conclusion, our study has shown that there is no evidence to support the hypothesis that the CVM method can predict the amount of craniofacial growth in girls with Class II malocclusion.

## References

- McNamara, J.A. (1981) Components of Class II malocclusion in children 8–10 years of age. *Angle Orthodontist*, 51, 177–202.
- Thiruvenkatachari B., Harrison, J.E., Worthington, H.V. and O'Brien, K.D. (2013) Orthodontic treatment for prominent upper front teeth (Class II malocclusion) in children. *Cochrane Database of Systematic Reviews*, CD003452. doi:10.1002/14651858.CD003452.pub3
- Pancherz, H. and Hägg, U. (1985) Dentofacial orthopedics in relation to somatic maturation. An analysis of 70 consecutive cases treated with the Herbst appliance. *American Journal of Orthodontics and Dentofacial Orthopedics*, 88, 273–287.
- Baccetti T., Franchi, L. and Kim, L.H. (2009) Effect of timing on the outcomes of 1-phase nonextraction therapy of Class II malocclusion. *American Journal of Orthodontics and Dentofacial Orthopedics*, 136, 501–509.
- Cozza, P., Baccetti, T., Franchi, L., De Toffol, L. and McNamara, J.A. Jr. (2006) Mandibular changes produced by functional appliances in Class II malocclusion: a systematic review. *American Journal of Orthodontics and Dentofacial Orthopedics*, 129, 599.e1–12.
- Houston, W.J.B., Miller, J.C. and Tanner, J.M. (1979) Prediction of the timing of the adolescent growth spurt from ossification events in hand-wrist films. *British Journal of Orthodontics*, 6, 145–152.
- Fishman, L.S. (1982) Radiographic evaluation of skeletal maturation. A clinically oriented method based on hand-wrist films. *Angle Orthodontist*, 52, 88–112.
- Lamparski, D.G. (1972) Skeletal Age Assessment Utilizing Cervical Vertebrae. Thesis, University of Pittsburgh.
- Franchi, L., Baccetti, T. and McNamara, J.A. (2000) Mandibular growth as related to cervical vertebral maturation and body height. *American Journal of Orthodontics and Dentofacial Orthopedics*, 118, 335–340.
- Baccetti, T., Franchi, L. and McNamara, J.A. (2005) The cervical vertebral maturation (CVM) method for the assessment of optimal treatment timing in dentofacial orthopedics. *Seminars in Orthodontics*, 11, 119–129.
- Dawson, B. and Trapp, R.G. (2004) *Basic and Clinical Biostatistics*. Lange Medical Books/McGraw-Hill. Medical Publishing Division, New York.
- Uysal, T., Ramoglu, S.I., Basciftci, F.A. and Sari, Z. (2006) Chronologic age and skeletal maturation of the cervical vertebrae and hand-wrist: is there a relationship? *American Journal of Orthodontics and Dentofacial Orthopedics*, 130, 622–628.
- Lai, E.H., Liu, J.P., Chang, J.Z., Tsai, S.J., Yao, C.C., Chen, M.H., Chen, Y.J. and Lin, C.P. (2008) Radiographic assessment of skeletal maturation stages for orthodontic patients: hand-wrist bones or cervical vertebrae? *Journal of Formosa Medical Association*, 107, 316–325.
- Soegiharto, B.M., Cunningham, S. J. and Moles, D.R. (2008) Skeletal maturation in Indonesian and white children assessed with hand-wrist and cervical vertebrae methods. *American Journal of Orthodontics and Dentofacial Orthopedics*, 134, 217–226.
- Gabriel, D.B., Southard, K.A., Qian, F., Marshall, S.D., Franciscus, R.D. and Southard, T.E. (2009) Cervical vertebrae maturation method: poor reproducibility. *American Journal of Orthodontics and Dentofacial Orthopedics*, 136, 478–480.
- Nestman, T.S., Marshall, S.D., Qian, F., Holton, N., Franciscus, R.G. and Southard, T.E. (2011) Cervical vertebrae maturation method morphologic criteria: poor reproducibility. *American Journal of Orthodontics and Dentofacial Orthopedics*, 140, 182–188.
- Zhao, X.G., Lin, J., Jiang, J.H., Wang, Q. and Ng, S.H. (2012) Validity and reliability of a method for assessment of cervical vertebral maturation. *Angle Orthodontist*, 82, 229–234.
- Cook, J.A. (2009) The challenges faced in the design, conduct and analysis of surgical randomised controlled trials. *Trials*, 10, 9. doi:10.1186/1745-6215-10-9.
- Farrokhyar, F., Karanicolas, P.J., Thoma, A., Simunovic, M., Bhandari, M., Devereaux, P.J., Anvari, M., Adili, A. and Guyatt, G. (2010) Randomized controlled trials of surgical interventions. *Annals of Surgery*, 251, 409–416.
- Beit, P., Peltomäki, T., Schätzle, M., Signorelli, L. and Patcas, R. (2013) Evaluating the agreement of skeletal age assessment based on hand-wrist and cervical vertebrae radiography. *American Journal of Orthodontics and Dentofacial Orthopedics*, 144, 838–847.
- Prahl-Andersen, B. and Kowalski, C.J. (1973) A mixed longitudinal, interdisciplinary study of the growth and development of Dutch children. *Growth*, 37, 281–295.
- Bland, J.M. and Altman, D.G. (1986) Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, 327, 307–310.
- Hassel, B. and Farman, A.G. (1995) Skeletal maturation evaluation using cervical vertebrae. *American Journal of Orthodontics and Dentofacial Orthopedics*, 107, 58–66.
- Fleiss, J.L. (1981) *Statistical Methods for Rates and Proportions*. John Wiley & Sons, New York, pp. 212–236.
- O'Reilly, M. and Yanniello, G.J. (1988) Mandibular growth changes and maturation of cervical vertebrae—a longitudinal cephalometric study. *Angle Orthodontist*, 58, 179–184.
- Santiago, R.C., de Miranda Costa, L.F., Vitral, R.W., Fraga, M.R., Bolognese, A.M. and Maia, L.C. (2012) Cervical vertebral maturation as a biologic indicator of skeletal maturity. *Angle Orthodontist*, 82, 1123–1131.
- Singh, I.J., Savara, B.S. and Miller, P.A. (1967) Interrelations of selected measurements of the face and body in pre-adolescent and adolescent girls. *Growth*, 31, 119–131.
- Bergersen, E.O. (1972) The male adolescent facial growth spurt: its prediction and relation to skeletal maturation. *Angle Orthodontist*, 42, 319–338.
- Howell, W.W. (1952) A factorial study of constitutional type. *American Journal of Physical Anthropology*, 10, 91–118.
- Mitani, H. and Sato, K. (1992) Comparison of mandibular growth with other variables during puberty. *Angle Orthodontist*, 62, 217–222.
- Ball, G., Woodside, D., Tompson, B., Hunter, W.S. and Posluns, J. (2011) Relationship between cervical vertebral maturation and mandibular growth. *American Journal of Orthodontics and Dentofacial Orthopedics*, 139, e455–e461.
- Baccetti, T., Franchi, L. and McNamara, J.A. Jr. (2002) An improved version of the cervical vertebral maturation (CVM) method for the assessment of mandibular growth. *Angle Orthodontist*, 72, 316–323.
- De Groot, L.J. (1993) Effects of irradiation on the thyroid gland. *Endocrinology Metabolism Clinics of North America*, 22, 607–615.
- Patcas, R., Signorelli, L., Peltomäki, T. and Schätzle, M. (2013) Is the use of the cervical vertebrae maturation method justified to determine skeletal age? A comparison of radiation dose of two strategies for skeletal age estimation. *European Journal of Orthodontics*, 35, 604–609.
- Buschang, P.H., Jacob, H.B. and Demirjian A. (2013) Female adolescent craniofacial growth spurts: real or fiction? *European Journal of Orthodontics*, 35, 819–825.