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Growth of the cervical vertebrae in girls from 8 to 17 years. A longitudinal study

Müge Altan, Öykü Nebioğlu Dalcı and Haluk İşeri
Department of Orthodontics, School of Dentistry, University of Ankara, Turkey

Correspondence to: Haluk İşeri, Ankara Üniversitesi, Diş Hekimliği Fakültesi, Ortodonti Anabilim Dalı, Beşevler, Ankara 06500, Turkey. E-mail: iseri@ankara.edu.tr

SUMMARY An important criterion of orthodontic diagnosis is the determination of the skeletal maturation stage. The cervical vertebral maturation (CVM) method is presented as an alternative to skeletal maturation determination. However, studies published to date concerning CVM have generally been cross-sectional. The aim of this investigation was to longitudinally evaluate growth and development with the CVM method. Lateral cephalometric radiographs of 41 girls, aged 9–16 years, collected between 1978 and 1984 were used to evaluate changes in C2, C3, and C4 dimensions. The mean values, standard deviations, maximum and minimum values of cervical vertebrae growth, and growth rate were calculated for every age and age interval. Cumulative growth increment was determined by summing annual mean values for each parameter. CVM stages were initially evaluated according to the method of Lamparski. The time differences between the following CVM stages were evaluated with a paired *t*-test.

The total length increment was distinct for C2 but similar for C1, C3, and C4. Total length increments reached their maximum between CVM stages 2 and 3, except for C3. The total length increment of C3 reached its peak 1 year earlier. The height increments of the spinose processes of C2, C3, and C4 were similar. The results showed that height increments were greater than length increments, which was due to changes in the anatomical pattern. Vertical growth displayed a decreasing trend from the upper to the lower cervical vertebrae. Determination of skeletal maturation from dimensional measurements and anatomical changes of the cervical vertebrae will facilitate orthodontic evaluation by eliminating the need for hand–wrist films and, therefore, decrease the patient's exposure to radiation.

Introduction

Accurate diagnosis is essential for treatment planning and achieving successful treatment results. One important criteria of orthodontic diagnosis is the determination of the skeletal maturation stage, i.e. the growth potential of the patient. Determination of the pubertal growth stage, especially in functional and orthopaedic treatment of anomalies characterized by skeletal and dentoalveolar malocclusions, is important for treatment prognosis.

Sexual maturation characteristics, chronological age, dental development, height, weight, and skeletal development are the criteria used to assess growth potential. Although some investigators (Rose, 1960; Bowden, 1977; Houston *et al.*, 1979; Bishara, 2000) criticized the use of biological means such as maturation stages of the short bones of the hand–wrist and skeletal age, these are widely accepted and used to determine the timing of individual growth (Helm *et al.*, 1971; Chapman, 1972; Grave, 1973; Grave and Brown, 1976; Singer, 1980; Demirjian *et al.*, 1985).

It has been stated that bones other than those in the hand–wrist may be used to determine skeletal maturation. Lamparski (1972) stated that the use of the cervical vertebrae is as valid as those of the hand–wrist bones in the assessment of skeletal maturation stages and developed a series of standards for the cervical vertebral maturation (CVM) stages of girls and boys. O'Reilly and Yanniello (1988) evaluated the relationship between maturation of the cervical vertebrae and mandibular growth and found a significant increase in mandibular growth within specific maturation stages of the cervical vertebrae. Hassel (1991) and Hassel and Farman (1995) indicated that the shapes of the cervical vertebrae change during each stage of skeletal growth and stated that skeletal maturation stages and residual growth potential of an individual can be determined in this way. Franchi *et al.* (2000) and Baccetti *et al.* (2002, 2003, 2005) reported that the CVM method can be used as a biological indicator both for mandibular and for somatic maturation. Mito *et al.* (2002) determined a regression formula to obtain cervical vertebral bone age, and Mito *et al.* (2003) and Chen *et al.* (2004, 2005) developed formulae using regression analysis to predict mandibular length increment using cervical vertebrae.

The cervical vertebrae can easily be seen on lateral cephalometric radiographs, which are routinely recorded for most orthodontic patients. Determination of skeletal maturation from dimensional measurements and anatomical changes of cervical vertebrae will facilitate orthodontic evaluation, eliminate the need for hand–wrist films, and, therefore, decrease the patient's radiation exposure. A detailed knowledge of the growth of the cervical vertebrae is essential in this respect, but studies published to date are generally cross-sectional (Lamparski, 1972; Hassel, 1991; Hellsing, 1991; Hassel and Farman, 1995; San Roman *et al.*, 2002). Therefore, the aim of this study was to longitudinally evaluate the growth and development of the cervical vertebrae.

Materials and methods

The material of this study included lateral cephalometric radiographs of 41 girls, aged 9–16 years, selected from a series of records, collected from 155 subjects between 1978 and 1984, from the archives of the Department of Orthodontics, University of Ankara. The records were taken yearly, during the observation period, except for 1980. The distribution of individuals is shown in Table 1.

Table 1 Distribution of the study sample.

Follow-up period (years)	Number of subjects	Number of cephalometric films
6	12	72
5	6	30
4	8	32
3	15	45
Total	41	179

Reference points on the vertebrae were marked on acetate paper by one author (MA), using a soft 0.3 mm pencil. The co-ordinates for reference points were transferred to a computer, using a Genius NewSketch 1212HR digitizer (KYE Systems America Corporation, Miami, Florida, USA) with ±0.01 sensitivity. Measurements were made with the PorDios cephalometric system (Institute of Orthodontic Computer Science, Middelfart, Denmark) using the digitized co-ordinates.

CVM was assessed from lateral cephalometric radiographs using the criteria defined by Lamparski (1972) and developed by Hassel (1991) and Hassel and Farman (1995). CVM was evaluated in six categories (Figure 1).

The vertebral maturation stages of the individuals were evaluated on the second (C2), third (C3), and fourth (C4) cervical vertebrae. The distribution of individuals according to CVM stages is shown in Table 2.

In this study, the age groups were defined by combining all observations within 1 year intervals starting with 7.50–8.49 years, which was designated age 8. For age interval groups, 1 year observation intervals were defined by the interval midpoints. The first age-interval group, '8.5 years' comprised all 1 year intervals with a midpoint in the 1 year interval 8–9 years. As serial follow-up was made, in the 9-year-old group, an 8.25-year-old patient and, in the 8.5-year-old group, a 7.92-year-old patient were included. Descriptive statistical data concerning age and age-interval groups are shown in Tables 3–6. Annual growth rate was determined as Rate = Increment/Observation period (years).

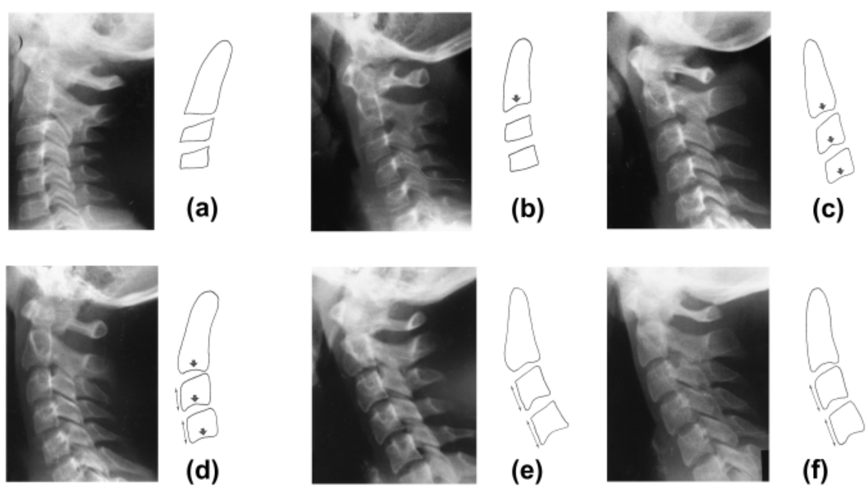

Figure 1 Cervical vertebral maturation stages: stage 1: inferior borders of C2, C3, and C4 were flat and the vertebral bodies were wedge shaped (a). Stage 2: concavities were developing in the inferior borders of C2 and C3. The inferior border of C4 was flat. The bodies of C3 and C4 were nearly rectangular in shape (b). Stage 3: concavity in the inferior borders of C2 and C3 was distinct. A concavity was beginning to develop in the inferior border of C4. The bodies of C3 and C4 were rectangular in shape (c). Stage 4: distinct concavities were seen in the inferior borders of C2, C3, and C4. The vertebral bodies of C3 and C4 were becoming squarer in shape (d). Stage 5: more accentuated concavities were seen in the inferior borders of C2, C3, and C4. Bodies of C3 and C4 were nearly square in shape (e). Stage 6: deep concavities were seen in the inferior borders of C2, C3, and C4. The bodies of C3 and C4 were square or were greater in vertical dimension than in horizontal dimension (f).

Table 2 Distribution of the study sample according to cervical vertebral stages.

Vertebral stages	Number of subjects
Stage 1	41
Stage 2	33
Stage 3	27
Stage 4	32
Stage 5	21
Stage 6	25
Total	179

Table 3 Age groups.

Group	*n*	Mean	SD	Minimum	Maximum
8	5	7.97	0.40	7.58	8.42
9	11	8.85	0.37	8.25	9.42
10	22	9.94	0.25	9.58	10.42
11	25	10.90	0.24	10.50	11.33
12	27	11.90	0.23	11.50	12.33
13	21	12.96	0.23	12.58	13.42
14	32	13.93	0.22	13.50	14.33
15	17	14.94	0.21	14.58	15.25
16	13	15.89	0.27	15.50	16.25
17	5	16.93	0.30	16.67	17.33
18	1	18.25			

Table 4 Age interval groups.

Group	*n*	Mean	SD	Minimum	Maximum
8.5	3	8.21	0.29	7.92	8.50
9.5	9	9.21	0.30	9.00	9.92
10.5	11	10.44	0.19	10.13	10.71
11.5	14	11.36	0.21	11.00	11.67
12.5	10	12.45	0.25	12.04	12.88
13.5	17	13.40	0.22	13.00	13.79
14.5	14	14.43	0.23	14.04	14.71
15.5	12	15.41	0.24	15.08	15.75
16.5	5	16.40	0.31	16.13	16.79
17.5	1	17.71			

Table 5 Mean age of cervical vertebral stages.

Group	*n*	Mean	SD	Minimum	Maximum	Variation Katsayısı (%)
Stage 1	27	9.46	1.04	7.58	11.00	10.94
Stage 2	31	11.14	0.75	9.42	12.25	6.74
Stage 3	27	12.37	0.90	10.67	14.17	7.28
Stage 4	33	13.62	0.73	12.08	15.25	5.36
Stage 5	20	14.36	0.70	12.83	15.67	4.87
Stage 6	16	15.57	0.66	14.00	16.75	4.27

Table 6 Time difference between the cervical vertebral stages.

	n	Mean	SD	Paired *t*-test
s2–s1	20	1.84	0.97	***
s3–s2	18	1.40	0.40	***
s4–s3	22	1.37	0.42	***
s5–s4	16	1.09	0.16	***
s6–s5	13	1.10	0.29	***

***$P < 0.001$.

In cases of a missing annual observation, the corresponding intervals were deleted from the calculations. There was only one individual in the 18-year-old group, so this period was taken into consideration for only individual evaluation.

The reference points and cervical vertebral measurements used in the present study are shown in Figure 2. To determine the repeatability of reference point marking and digitization procedures, 20 cephalometric radiographs of 10 individuals were randomly chosen. The procedures were duplicated by one investigator (MA) after 1 month and repeatability coefficients were calculated. Coefficients for the cervical vertebral measurements (r^2) varied between 0.91 and 0.99.

The mean values, standard deviations, minimum and maximum values of cervical vertebrae growth, and growth rate were calculated for every age and age interval. Cumulative growth increments were determined by summation of the annual mean values for every parameter. The time differences between the following CVM stages were evaluated with a paired *t*-test (Winner, 1971).

Results

The distribution of the CVM stages of the subjects according to chronological age is shown in Figure 3. It can be seen that from the 41 individuals in the first stage, who were at the start of pubertal growth, 28 were 9–10 years old. In the second stage, in which pubertal growth was accelerated, most of the individuals ($n = 26$) were 11–12 years old. The pubertal growth peak was reached in the third stage of the cervical vertebral period. Eleven subjects in this period were 12 years old and nine were 13 years old. In the fourth stage, in which the growth rate decelerated, individuals ($n = 18$) were mostly 14 years old. In the fifth stage, the individuals were near the end of their pubertal growth; 10 subjects in this period were 14 years old and eight 15 years old. Pubertal growth was completed at the sixth stage and comprised mostly 16-year-old individuals ($n = 12$). The mean chronological ages of these individuals according to CVM stages are shown in Table 5.

A comparison of the time differences between following CVM stages is displayed in Table 6. Time differences between

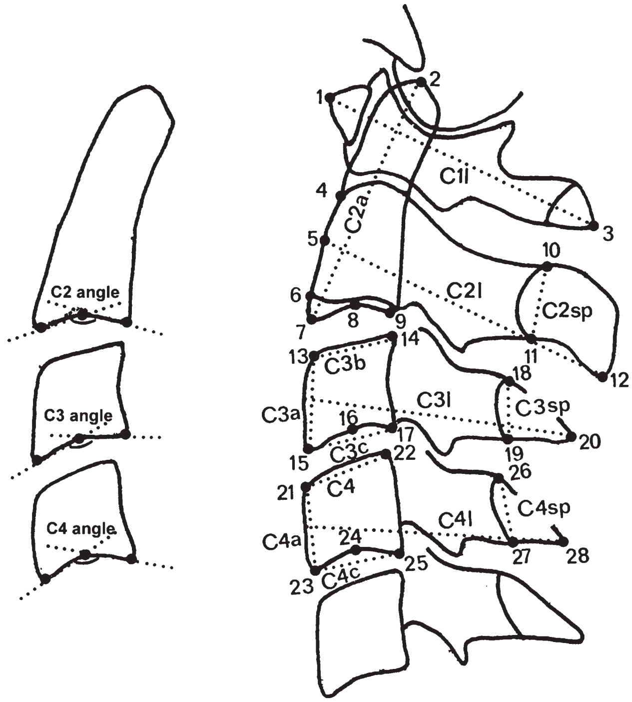

Figure 2 Reference points for cephalometric vertebral measurements: 1. C1a: extreme anterior point on the anterior tubercle of atlas. 2. C2ap: the apex of the odontoid process of c2. 3. C1spp: extreme posterior point on the dorsal arch of atlas. 4. C2sl: the intersection points of the upper lamina border and anterior surface of the odontoid process on c2. 5. C2ml: the midpoint between the intersection points of the upper and lower lamina borders with the odontoid process on c2. 6. C2il: the intersection points of the lower lamina border and anterior surface of the odontoid process on c2. 7. C2ai: the most infero-anterior point on the body of c2. 8. C2im: the deepest point on the inferior border of c2. 9. C2pi: the most infero-posterior point on the body of c2. 10. C2sps: the uppermost point of the radiographic cross-sectional outline of the posterior arch of c2. 11. C2spi: the lowermost point of the radiographic cross-sectional outline of the posterior arch of c2. 12. C2spp: the extreme posterior point of the radiographic cross-sectional outline of the posterior arch of c2. 13. C3as: the most supero-anterior point on the body of c3. 14. C3ps: the most supero-posterior point on the body of c3. 15. C3ai: the most infero-anterior point on the body of c3. 16. C3im: the deepest point on the inferior border of c3. 17. C3pi: The most infero-posterior point on the body of c3. 18. C3sps: the uppermost point of the radiographic cross-sectional outline of the posterior arch of c3. 19. C3spi: the lowermost point of the radiographic cross-sectional outline of the posterior arch of c3. 20. C3spp: the extreme posterior point of the radiographic cross-sectional outline of the posterior arch of c3. 21. C4as: the most supero-anterior point on the body of c4. 22. C4ps: the most supero-posterior point on the body of c4. 23. C4ai”: the most infero-anterior point on the body of c4. 24. C4im: the deepest point on the inferior border of c4. 25. C4pi: the most infero-posterior point on the body of c4. 26. C4sps: the uppermost point of the radiographic cross-sectional outline of the posterior arch of c4. 27. C4spi: the lowermost point of the radiographic cross-sectional outline of the posterior arch of c4. 28. C4spp: the extreme posterior point of the radiographic cross-sectional outline of the posterior arch of c4. Cervical vertabral measurements: 1. C1l: total length of the cervical first vertebrae (atlas). The distance between the extreme points of the anterior and posterior arches. 2. C2l: total length of cervical second vertebrae (axis). The distance between the extreme posterior point of spinose process and midpoint between the anterior lamina points that intersects the anterior border of odontoid process. 3. C3l: total length of cervical third vertebrae. The distance between the midpoint of the anterior border and the extreme posterior point of the spinose process. 4. C4l: total length of cervical fourth vertebrae. The distance between the midpoint of the anterior border and the extreme posterior point of the spinose process. 5. C2sp: height of spinose process of cervical second vertebrae. 6. C3sp: height of spinose process of cervical third vertebrae. 7. C4sp: height of spinose process of cervical fourth vertebrae. 8. C2a: anterior height of cervical second vertebrae (axis) body. 9. C3a: anterior height of the cervical third vertebrae body. 10. C4a: anterior height of cervical fourth vertebrae body. 11. C3b: superior body length of cervical third vertebrae. 12. C4b: superior body length of cervical fourth vertebrae. 13. C 3c: inferior body length of cervical third vertebrae. 14. C4c: inferior body length of cervical fourth vertebrae. 15. C2 inferior border angle: the angle between the lowest points of the anterior and posterior borders of second cervical vertebra bodies and the midpoint of the inferior border, with the vertex at the midpoint. 16. C3 inferior border angle: the angle between the lowest points of the anterior and posterior borders of third cervical vertebral bodies and the midpoint of the inferior border, with the vertex at the midpoint. 17. C4 inferior border angle: the angle between the lowest points of the anterior and posterior borders of fourth cervical vertebral bodies and the midpoint of the inferior border, with the vertex at the midpoint.

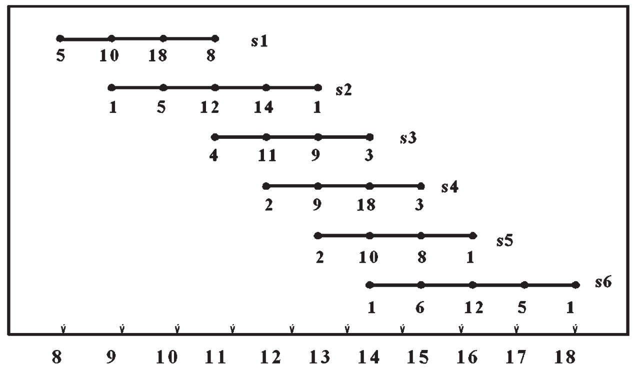

Figure 3 Cervical vertebral maturation stage distribution of individuals according to chronological age.

the following CVM periods were statistically significant ($P < 0.001$).

Cervical vertebra growth increment and rate

Total length increments of C1, C2, C3, and C4 between 8 and 17 years are shown in Figure 4. The greatest amount of growth, 11 mm, was observed for C2. However, the observed mean growth for C1, C3, and C4 was approximately 7 mm.

The mean values for the annual growth rate of C1, C2, C3, and C4 lengths are shown in Figure 4a. It was found that C1 and C4 reached their peak at approximately 11.5 years of age (C1 = 1.3 mm/year, C4 = 1.7 mm/year). C3 reached its maximum growth rate at 10.5 years of age (2 mm/year). It was found that C2 did not have a distinct growth rate peak but a more linear growth rate curve. The length increment rate of the cervical vertebrae decelerated to 0–0.2 mm/year by the age of 15.5 years. C1, C2, and C4 reached their peak between CVM stages s2 and s3 and C3 between s1 and s2. After s6 (15.5–16 years), increases in length ceased.

Figure 5a shows that the mean increase in the height of the spinose processes of C2, C3, and C4 was approximately 5 mm. Figure 5b displays height increment rates of the

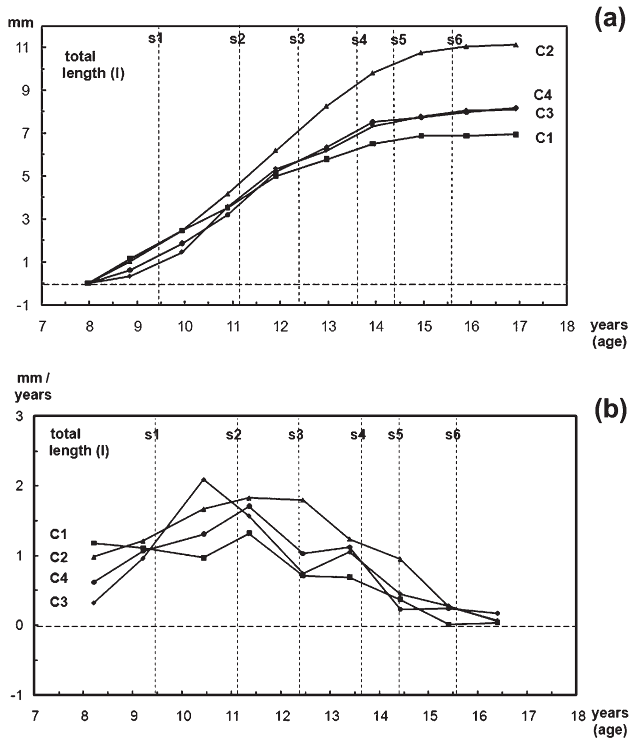

Figure 4 Total length increment curves of C1, C2, C3, and C4 (a) and their annual growth rates (b).

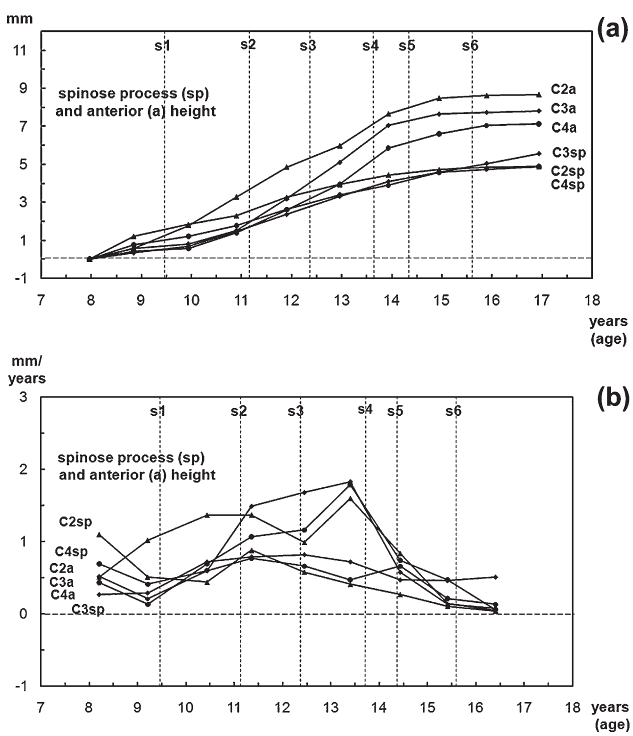

Figure 5 Spinose process and anterior height increment curves of C2, C3, and C4 (a) and (b) their mean growth rates curves.

spinose processes of C2, C3, and C4. Most growth rate increases were seen between s2 and s3. However, no distinct peaks were observed, except for C2. After s6, a slight height increase, of nearly 0.1–0.5 mm/year, was determined.

The anterior height increments of C2, C3, and C4 bodies are shown in Figure 5a. The mean height increments of C2, C3, and C4 were 8.66, 7.82, and 7.12 mm, respectively. Annual mean anterior height increment rates of the vertebra bodies are displayed in Figure 5b. All the vertebrae reached their peak, at approximately 13.5 year of age, between s3 and s4, with similar means (2 mm/year). However, at 15.5 years of age (s5) deceleration began for all vertebrae and anterior height increments ceased at 16.5 years (s6).

Total superior length increases of C3 and C4 bodies are displayed in Figure 6a. For both vertebrae, the increase was approximately 2 mm. The annual mean superior length increment rates of C3 and C4 vertebrae bodies are shown in Figure 6b. C3 and C4 vertebrae reached their peak, at approximately 11.5 year of age. Their growth rate curves fluctuated. Superior length increments of C3 and C4 vertebrae terminated approximately at the age of 15 years. The superior length increment rates of C3 and C4 peaked between s2 and s3 and terminated at s5.

Inferior length increases of C3 and C4 bodies are displayed in Figure 6a. Total increases for C3 and C4 were 1.7 and 2.7 mm, respectively. The annual mean inferior length increment rates of C3 and C4 are shown in Figure 6b. Both vertebrae reached their peak at approximately 11.5 years of age (0.5 mm/year and 0.6 mm/year). Inferior length increment ceased at approximately 16 years. The peak of inferior length increment was observed between s2 and s3 and termination occurred approximately during s5 and s6.

Figure 7 displays the change in the inferior border angles of C2, C3, and C4. All three angles decreased gradually from 8 to 16 years of age. With the decrease in these angles, their inferior borders became more concave.

Discussion

It is known that during growth and development, dentofacial structures have different growth rates. This is fundamental especially in the treatment and stability of skeletal anomalies. Many methods have been suggested to predict growth potential. Previous studies have shown that the most common clinical method is evaluation of hand–wrist radiographs.

The aim of this study was to critically analyse the CVM method as an alternative to other skeletal maturation determination methods, in an effort to improve orthodontic diagnosis. This method uses the anatomical structures of the cervical vertebrae that are already recorded on cephalometric radiographs. A demonstration of the clinical reliability of the CVM method would reduce or even eliminate the need for hand–wrist radiographs. This procedure not only

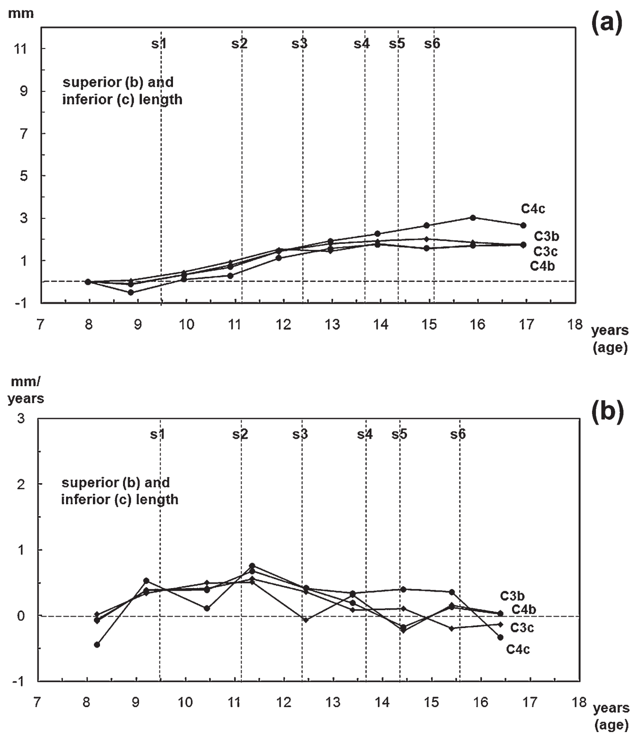

Figure 6 Superior and inferior length increment curves of C3 and C4 (a) and their mean growth rate curves.

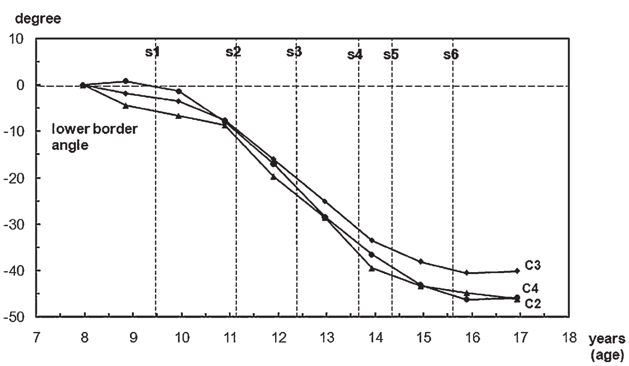

Figure 7 Lower border angle increment curves of C2, C3, and C4.

provides a diagnostic tool for the orthodontist but also decreases the radiation dose to the patient.

In this study, growth and development of the cervical vertebrae were evaluated on longitudinal material in order to obtain detailed information concerning the change in anatomical structures and the shape of the cervical vertebrae in different age groups.

Lamparski (1972), in a cross-sectional study, investigated the correlations between cervical vertebrae and hand–wrist maturation stages and developed a series of standards for the developmental stages of C2–C6. That author stated that future work was required to refine the standards and determine other maturity indicators. He suggested that a longitudinal sample be employed to eliminate much of the individual variation that was present in his study. Hassel (1991) and Hassel and Farman (1995) analysed the CVM stage standards developed by Lamparski (1972). However, these were cross-sectional and comprised 220 girls and boys between the ages of 8 and 18 years.

Hellsing (1991), in a cross-sectional study, evaluated cervical vertebral growth in a sample of 8-, 11-, and 15-year-old children. Height and length increments of the cervical vertebrae, as well as correlations between cervical vertebral dimensions and height at different ages were investigated. From the few longitudinal investigations concerning growth of the cervical vertebrae, one of the most comprehensive was that by Eriksen (1992). In that study, the post-natal growth of the cervical vertebral column was defined, whereas CVM was not evaluated.

As mentioned, the studies on cervical vertebral growth and maturation are mainly cross-sectional. Therefore, the present research comprised a longitudinal sample to eliminate individual variability, which is present in cross-sectional studies. In the current research, dental or skeletal classification of the samples was not considered.

In order to determine the CVM of the individuals, the six maturation stages defined by Lamparski (1972) were used. These stages were classified by Hassel (1991) and Hassel and Farman (1995) as ‘initiation’, in which a major amount of adolescent growth is expected, ‘acceleration’, in which growth is accelerating and a large amount of adolescent growth is expected, ‘transition’, in which the peak of pubertal growth is reached and a mean/intermediate amount of adolescent growth is expected, ‘deceleration’, in which growth rate decelerates and limited adolescent growth is expected, ‘maturation’, in which very little amount of adolescent growth is expected, and ‘completion’, in which growth is complete.

Assessment of individual skeletal maturation using the CVM benefits from cervical vertebrae displaying different anatomical shapes and characteristics in different maturation stages (Lamparski, 1972; Hassel, 1991; Hellsing, 1991; Hassel and Farman, 1995). Cervical vertebral bodies change from a wedge to a rectangle and then to a square shape and then have greater dimensions vertically than horizontally. The inferior vertebral borders are flat when most immature and become concave with maturation. The concavities become more distinct as maturation occurs. The vertebral measurements used in this study were chosen to reflect these anatomical changes that occur with growth.

It was found that the total length increment was distinct for C2 but similar for the other cervical vertebrae (Figure 4a). Total length increments reached their maximum between s2 and s3, except for C3. The total length increment of C3 reached its peak 1 year earlier (Figure 4b). The height increments of the spinose processes of C2, C3, and C4 were similar. The growth rate curves were almost constant (Figure 5a and 5b).

In the current study, the changes in C2, C3, and C4 body height and length between the ages 8 and 17 were evaluated longitudinally. Hellsing (1991), in her cross-sectional study, used only one measurement for the height increment of C2 and concluded that between the ages of 8 and 15 years, the mean increase was 6 mm. For C3 and C4, between the ages of 8 and 15 years, the mean anterior height increment was found to be 7.3 and 6 mm, respectively. The results of the current study are in agreement of those findings, except for the anterior height increment of C2, which was found to be 8.66 mm.

Vertical growth decreased from the upper to the lower cervical vertebrae. In addition, the inferior border angle decreased as a result of the anterior and posterior height increments of C2–C4 (Figure 7).

The results of the present study indicate that the increase in cervical vertebral height was three times greater than the increase in length. Lamparski (1972) reported that the cervical vertebral shape changes from a wedge to a rectangle and then to a square during growth. This anatomical change depends on superior and inferior length increments being less than anterior and posterior height increments.

Data from the present longitudinal sample show that during the adolescent period, the bodies and inferior borders of C2, C3, and C4 undergo a significant change. Thus, the standards developed from cross-sectional material by Lamparski (1972) are also confirmed longitudinally.

It has been shown that the longitudinal growth processes of the cervical vertebral bodies are similar to long bones. Vertical growth of the cervical vertebrae occurs as a result of growth of their superior and inferior cartilaginous layers. The increase in growth was bilateral (Bick and Copel, 1950; Knutsson, 1961; Gooding and Neuhauser, 1965).

The size increments of the cervical vertebrae follow a somatic pattern and reach their final size at maturation (Tulsi, 1971; Israel, 1973; Taylor, 1975). The finding of the present study showed that size continued to increase until 15–16 years of age. This period coincided with the growth termination of height and the sutures in girls (Björk, 1966; Işeri and Solow, 1990). Another finding was the variation in growth rate in various parts of the cervical vertebrae. According to the data, the anterior height increment due to condral growth of the cervical vertebral bodies reached its maximum between s3 and s4, generally just before s4, and superior and inferior length increments due to appositional growth reached their maximum growth rate between s2 and s3. The maximum rate period for length increment was reached 1.5–2 years before height increment. Similar findings were reported by Eriksen (1992) in a longitudinal study that included 41 males and 40 females between the ages of 5 and 25 years. It was stated that appositional growth and increase in height of the cervical vertebrae, reached a maximum rate at the pubertal period, close to each other. However, it was shown that maximum rate for height increment with condral growth was reached later. Another finding similar to the present study was that C3–C5 heights doubled their original size, whereas the increase of C1 height was relatively small.

Mitani and Sato (1992) analysed cervical vertebrae growth of 33 Japanese girls between the ages 9 and 14 years. As vertebral growth was evaluated only in the vertical dimension, it was concluded that the maximum cervical vertebral growth rate was between the ages of 10 and 12 years. However, in the current study, maximum growth rate was determined between the ages 12.5 and 13.5 years. This variation might be due to the use of different parameters. Mitani and Sato's (1992) vertebral size measurements also included the intervertebral space, whereas only the distance between the superior and inferior borders was measured in the present study. Mito *et al.* (2002) used lateral cephalograms of 176 girls and reported an accelerated increase in anterior and posterior vertebral body heights and vertebral body heights between the ages 10 and 13 years.

San Roman *et al.* (2002) evaluated the changes in the concavity of the lower border, height, and shape of cervical vertebrae bodies on lateral cephalometric radiographs of 958 children. Correlations between hand–wrist and CVM methods were also investigated. They found that the best vertebral parameter to estimate maturation was the concavity of the lower border of the body. The correlation between hand–wrist maturation and the CVM method was high, but the correlation was lower with the method of Lamparski (1972).

In a longitudinal study, Baccetti *et al.* (2002) analysed the morphology of the bodies of C2, C3, and C4 of 30 subjects. A new version of the CVM method was developed that included five maturational categories. With the results of their visual and cephalometric inspections, they concluded that the concavity in the lower border of C2 is not a distinctive feature of s2 compared with s1 and merged the first two stages into one. The advantage of this method is that it can be used if only one cephalogram is available and only C2–C4 are visible. In a more recent study (Baccetti *et al.*, 2005), a clinically improved version of the CVM method, again comprising six categories, was introduced and dentofacial treatment timing of different anomalies was examined.

The present findings correlate with the age groups in the study of Lamparski (1972) and with the typical criteria representing those age groups. Lamparski (1972) stated that the inferior border of all cervical vertebral bodies were flat in 10-year-old girls. In the present study, this stage was defined as s1 and the mean age for this period was 9.46. At 11 years, the inferior border of C2 became concave and the anterior height of C2 increases. This period was defined as s2 and the mean age was 11.14 years. The inferior border of C3 became concave at 12 years, which was defined in the present study as s3 and the mean age was 12.37. At 13 years of age, the concavity on the inferior border of C3 became distinct and the inferior border of C4 concave. According to the present data, this was classified as s4 and the mean age was 13.62 years. At 14 years of age, all the inferior borders of the cervical vertebrae became concave and the bodies are more square. This was categorized in the present study as s5 and the mean age was 14.36 years. In 15-year-old girls, the vertical heights of all vertebrae bodies were greater than their width. This was defined as s6 and the mean age was 15.56 years. Thus, the mean ages of the categories defined by Lamparski (1972) show similarities with the mean age of the groups in the present sample and with same standards as Lamparski's method.

Conclusions

The results of this longitudinal growth study in girls indicate that the cervical vertebrae show characteristic morphology at the six stages of CVM related to growth changes and thus can be used as an alternative method to determine skeletal maturation. The use of cervical vertebrae, which can easily be seen on lateral cephalometric radiographs, would eliminate the need for hand–wrist films, and therefore, the amount of radiation absorbed by the patient will decrease.

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