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Skeletal maturation determined by cervical vertebrae development

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SUMMARY The aim of this study was to determine the validity of cervical vertebrae radiographic assessment to predict skeletal maturation. Left hand-wrist and lateral cephalometric radiographs of 958 Spanish children from 5 to 18 years of age were measured. On the left hand-wrist radiographs the classification of Grave and Brown was used to assess skeletal maturation. Cervical vertebrae maturation was evaluated with lateral cephalometric radiographs using the stages described by Lamparski and by Hassel and Farman. A new method to evaluate the cervical maturation by studying the changes in the concavity of the lower border, height, and shape of the vertebral body was created.

Correlation coefficients were calculated to establish the relationship between skeletal maturation values obtained by the three classifications of vertebral and skeletal maturation measured at the wrist. All correlation values obtained were statistically significant ($P < 0.001$).

The results suggest that this new method to determine skeletal maturation is very reliable. A simple method based on morphological characteristics of the cervical vertebral bodies to evaluate the maturation stage has been designed. In the population investigated, this method is as accurate as the Hassel and Farman classification and superior to the Lamparski classification. The morphological vertebral parameter best able to estimate the maturation is the concavity of the lower border of the body.

Introduction

The clinical importance of evaluating skeletal maturation has long been recognized by health professionals (Grave and Brown, 1976; Hägg and Taranger, 1980; Hassel and Farman, 1995). Growth and development of humans is not uniform, but has periods of acceleration and deceleration. As far as orthodontics is concerned, by reliably determining maturation and growth stage a correct diagnosis can be obtained and appropriate treatment initiated.

Many authors have attempted to determine the best indicators of the degree of maturity. Sexual maturation characteristics (Fishman, 1979; Hägg and Taranger, 1980, 1982), chronological age (Taranger and Hägg, 1980), dental development (Hägg and Matsson, 1985; Sierra, 1987; Coutihno *et al*., 1993), height (Tanner *et al*., 1976), weight (Green, 1961), skeletal development (Grave and Brown, 1976; Travesí, 1977; Fishman, 1982; Muelas, 1990), and vertebral development (Lamparski, 1972; Vilar *et al*., 1994; Hassel and Farman, 1995; Garcia-Fernandez *et al*., 1998) are some of the parameters that have been used to identify the stage of growth.

Recently, the usefulness of lateral cephalometric radiographs to assess maturation has been studied (Lamparski, 1972; Vilar *et al*., 1994; Hassel and Farman, 1995; Garcia-Fernandez *et al*., 1998). Although scant data are available, these studies suggest that the cervical vertebrae may be a good indicator of maturity.

Skeletal maturation assessed on hand-wrist radiographs is classically considered as the best indicator of maturity (Chapman, 1972; Grave and Brown, 1976; Houston *et al*., 1979) and has been found to be closely related to the growth spurt. Its main drawback is that an additional radiograph is required. Although minimal radiation is associated with a hand-wrist radiograph, it would be ideal to assess the growth stage without additional radiography.

The aim of this investigation was to determine whether the morphological changes seen in the cervical vertebrae are as useful to determine the growth stage as the maturation stages assessed on hand-wrist radiographs in a Spanish sample. A new method to evaluate the skeletal maturation with the cervical vertebrae seen on the lateral cephalometric radiograph was also created.

Subjects and method

Subjects

More than 5000 patient files were initially reviewed. The final study population consisted of 958 subjects, all Caucasians (428 males, median age 11.6 years and 530 females, median age 11.5 years), who attended the Orthodontic Department of the Complutense University of Madrid between 1980 and 1996 and fulfilled the following criteria:

1. between 5 and 18 years of age;
2. hand-wrist and cephalometric radiographs available with high clarity and good contrast;
3. a time interval of less than one month between the radiographs;
4. no systemic disease that could affect general development;
5. no previous orthodontic treatment.

Radiographic analysis

All radiographs were analysed with a conventional negatoscope by the same observer. The radiographs were obtained with protective aprons (Rinn Corporation Dentisply International, Inc. Elgin, Illinois, USA).

Hand-wrist radiographs

The system developed by Grave and Brown (1976) and the growth curve of Björk and Helm (1967) were used to determine the stage of skeletal maturation in each patient (Figure 1).

Lateral cephalometric radiographs

To standardize the spinal position, all radiographs were obtained with the patient positioned so that the X-ray beam was perpendicular to the head. A mirror was positioned in front of the X-ray machine and the patient was instructed to look into it and not to rotate the head.

The odontoid process and the body of the cervical vertebrae were traced on acetate. The stage of vertebral maturation defined by the systems developed by Lamparski (1972) and Hassel and Farman (1995) was assigned to each radiograph. Intermediate stages were used in both systems.

In order to develop a new method to evaluate skeletal maturation, the anatomical changes observed in the concavity of the lower border, height, and shape of the vertebral body were also studied.

1. *Concavity of the lower border* was considered to be present when there was a distance of more than 1 mm between the middle of the lower border of the vertebral body and a line traced from the postero-inferior angle to the antero-inferior angle of the vertebral body. According to the concavity, six stages were defined: (1) all vertebrae have a flat lower border; (2) a concavity is present in the C_2 lower border; (3) a concavity is present in C_3 lower border; (4) C_2 and C_3 concavity increases and a concavity is present in C_4, C_5, and C_6; (5) concavity increases in all vertebrae; (6) a deep concavity is present in all vertebrae and the inferior angles are rounded (Figure 2).

2. *Vertebral body height* was calculated in C_3 and C_4 at the middle of the vertebral body. The lower border was considered to be the line traced from the postero-inferior angle to the antero-inferior angle of the vertebral body. Width was also calculated at the middle of the body (Figure 3). Four stages were defined: (1) height is less than 80 per cent of width; (2) height is between 80 and 99 per cent of width; (3) height and width are equal; (4) height is greater than width (Figure 4).

3. *The shape of the vertebral body* was calculated at C_3 and C_4 and the following stages were defined: (1) upper border is tapered from the

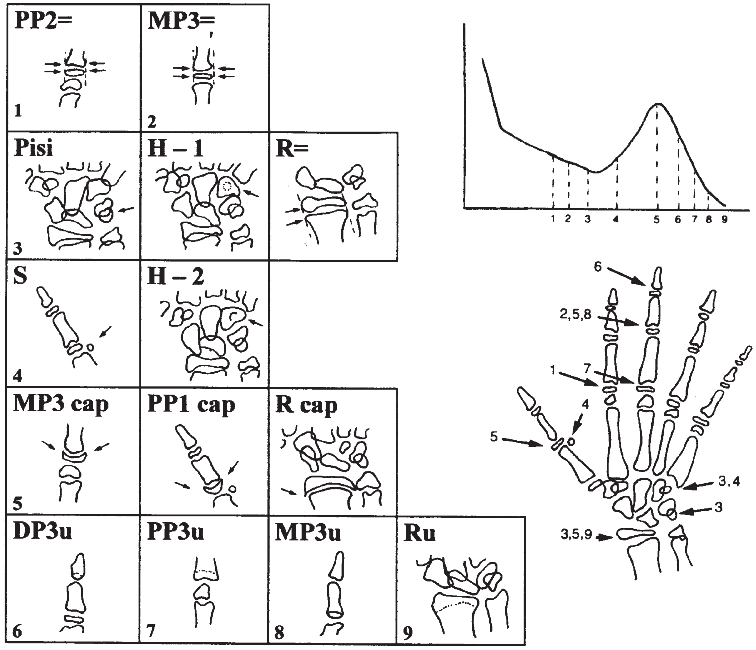

Figure 1 Classification of skeletal maturation (published with kind permission from Grave and Brown, 1976, American Journal of Orthodontics 69: 611–619) and growth velocity (Björk and Helm, 1967). The method is used taking a hand-wrist radiograph and checking which maturity markers are present. These markers indicate the current point of the growth curve of the child.

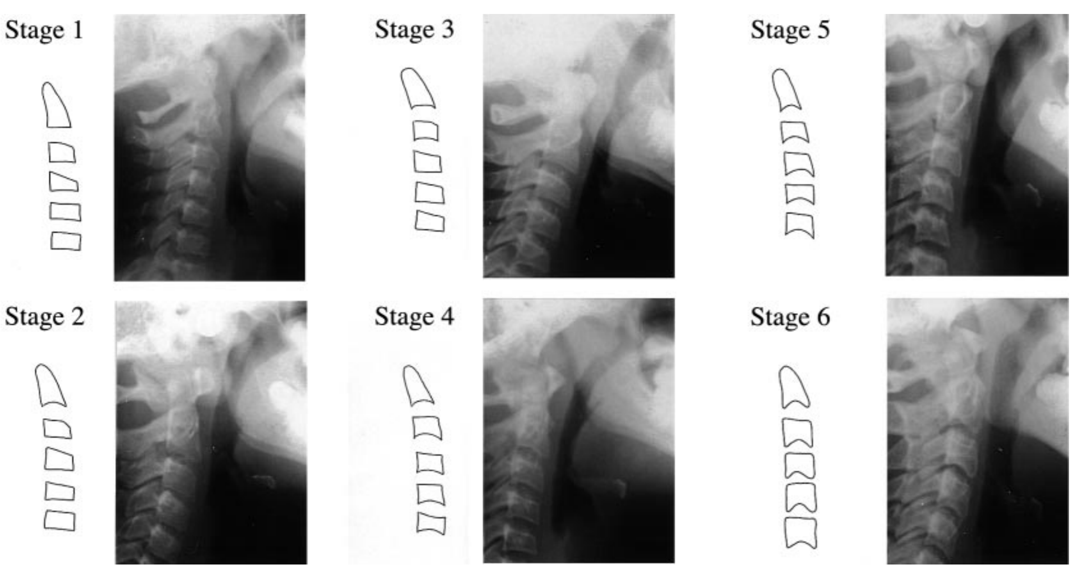

Figure 2 Cervical vertebrae maturation stages according to the concavity of the lower border of the vertebral body. (1) All vertebrae have a flat lower border; (2) a concavity is present in the C_2 lower border; (3) a concavity is present in C_3 lower border; (4) C_2 and C_3 concavity increases and a concavity is present in C_4, C_5, and C_6; (5) concavity increases in all vertebrae; (6) a deep concavity is present in all vertebrae and the inferior angles are rounded.

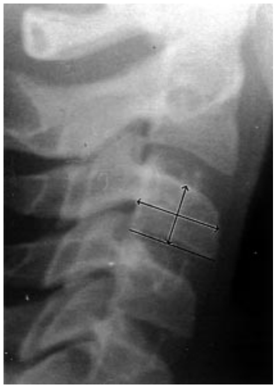

Figure 3 Method to measure height and width of the vertebral bodies.

posterior to the anterior and wedge-shaped; (2) wedge-shaped C_3 and nearly rectangular shaped C_4 with absence of supero-anterior angles; (3) rectangular shaped bodies; (4) nearly squared bodies; (5) squared bodies; (6) rectangular bodies with height greater than width (Figure 5).

Statistical method

Data were studied by means of SPSS 6.1 (SPSS; Chicago, Illinois, USA). Pearson correlation coeficients were calculated to establish the relationship between skeletal maturation values obtained by both classifications of vertebral maturation (Lamparski, 1972; Hassel and Farman, 1995) and the skeletal maturation measured at the wrist. Correlation between the vertebral lower border concavity, height, and shape and skeletal maturation measured at the wrist was also established. An estimation of wrist maturation as a function of concavity, height, and shape was carried out by means of a multiple regression equation. Correlation between this variable and skeletal maturation measured at the wrist was also established. The correlation found between Lamparski, and Hassel and Farman classifications, and the global variable with skeletal maturation measured in the wrist were compared with Fisher's z-test.

Intra-observer variability was calculated using Pearson's correlation coefficient between measurements of 50 patients with those performed in

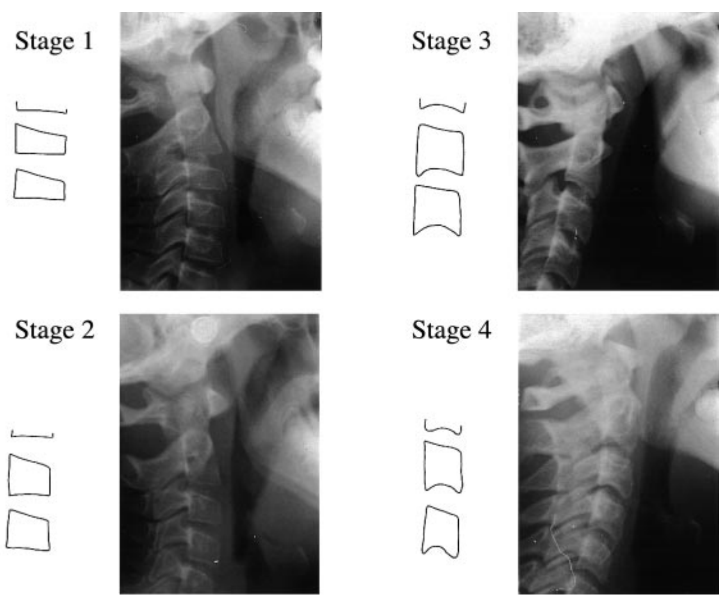

Figure 4 Cervical vertebrae maturation stages according to the vertebral body height. (1) Height is less than 80 per cent of width; (2) height is between 80 and 99 per cent of width; (3) height and width are equal; (4) height is greater than width.

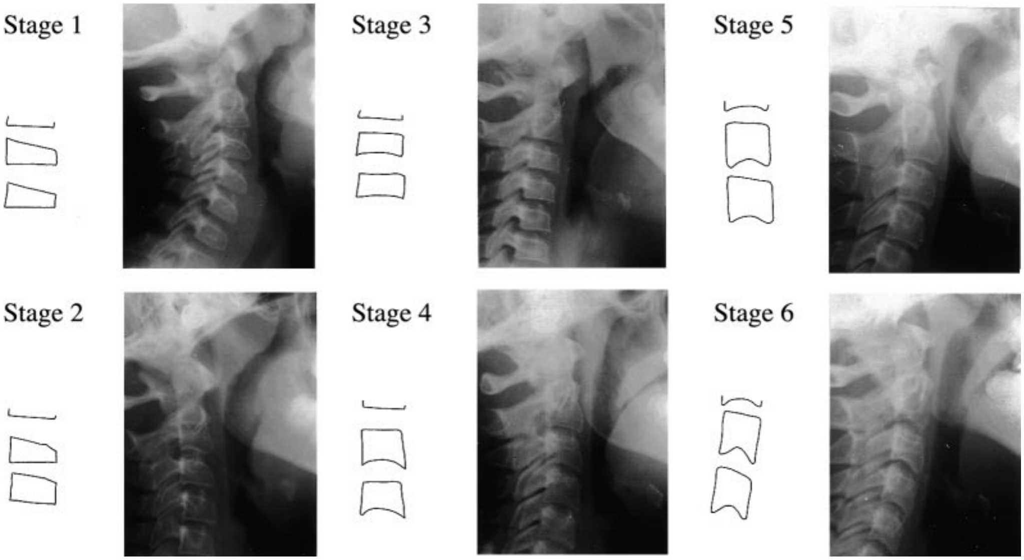

Figure 5 Cervical vertebrae maturation stages according to the shape of the vertebral body. (1) Upper border is tapered from the posterior to the anterior and wedge-shaped; (2) wedge-shaped C_3 and nearly rectangular shaped C_4 with absence of supero-anterior angles; (3) rectangular-shaped bodies; (4) nearly squared bodies; (5) squared bodies; (6) rectangular bodies with height greater than width.

the same patients three weeks later. Coefficients obtained ranged between 0.99 and 0.96 ($P < 0.001$).

Results

Skeletal maturation

The results of hand-wrist skeletal maturation are shown in Table 1. The most frequent in females was stage 5 (33.6 per cent), followed by 3 (15.8 per cent) and 4 (11.1 per cent). On the other hand, males were more frequently included in stage 3 (25 per cent), followed by 5 (19.4 per cent) and then 1 (17.3 per cent).

For Hassel and Farman's classification (Table 2), the most frequent stages were 3 and 2 in girls (24 and 23.8 per cent, respectively) and stage 2 in boys (33.2 per cent).

With respect to Lamparski vertebral classification (Table 3), stage 4 was the most frequent

Table 1 Sample distribution according to hand-wrist stages described by Grave and Brown (1976).

Maturation stage	Males (number of cases)	Females (number of cases)	Total (number of cases)
0	39	10	49
1	74	41	115
2	49	27	76
3	107	84	191
4	49	59	108
5	83	178	261
6	13	44	57
7	7	20	27
8	5	49	54
9	2	18	20

Table 2 Sample distribution according to vertebral maturation stages described by Hassel and Farman (1995).

Maturation stage	Males (number of cases)	Females (number of cases)	Total (number of cases)
1	99	82	181
1.5	26	18	44
2	142	126	268
2.5	11	12	23
3	100	127	227
3.5	7	18	25
4	24	57	81
4.5	5	7	12
5	6	60	66
5.5	3	7	10
6	5	16	21

Table 3 Sample distribution according to vertebral maturation stages described by Lamparski (1972).

Maturation stage	Males (number of cases)	Females (number of cases)	Total (number of cases)
1	80	64	144
1.5	0	8	8
2	9	45	54
2.5	55	3	58
3	7	118	125
3.5	0	10	10
4	118	155	273
4.5	8	11	19
5	116	93	209
5.5	8	6	14
6	27	17	44

both in males and females (27.6 and 29.2 per cent, respectively). Stage 5 was also common in males (27.1 per cent).

Correlation between hand-wrist skeletal maturation and different classifications of vertebral maturation

A good correlation was found between hand-wrist skeletal maturation and vertebral maturation assessed by the Hassel and Farman classification both in females and males ($r = 0.84$ and 0.77, respectively), although it was significantly better for females ($P < 0.01$). A lower correlation was found when Lamparski's classification was compared with hand-wrist skeletal maturation. Again, correlation was significantly higher in girls ($r = 0.79$) than in boys ($r = 0.69$; $P < 0.001$ compared with girls).

Correlation between hand-wrist skeletal maturation and anatomical parameters of the cervical vertebrae

Concavity of the lower border tended to have the highest correlation with hand-wrist maturation (females: $r = 0.82$; males: $r = 0.75$). A good correlation was also found when shape (females: $r = 0.74$; males: $r = 0.67$) and height (females: $r = 0.70$; males: $r = 0.60$) were assessed.

Hand-wrist skeletal maturation estimated by concavity, height, and shape

A multiple regression equation as a function of the concavity, height, and shape of the cervical vertebrae was found to estimate the hand-wrist skeletal maturation. In males, the best adjustment included the three variables: hand-wrist maturation stage = –0.838 + 0.771 concavity stage + 0.840 height stage + 0.229 shape stage.

However, in females the best adjustment included only two variables: hand-wrist maturation stage = 0.029 + 0.914 concavity stage + 0.745 height stage.

Skeletal maturation estimated by this method was found to have a good correlation with that calculated on the hand-wrist radiographs ($r = 0.85$ females, $r = 0.79$ males). Differences between the sexes were statistically significant ($P < 0.05$).

Comparison of correlation of the different methods of assessment of vertebral maturation with hand-wrist maturation (Table 4)

When the correlations were compared, the new method was found to have the highest correlation with the hand-wrist method although no statistical differences were found with the Hassel and Farman method. The Lamparski classification had a significantly lower correlation with the hand-wrist skeletal maturation method when compared both with the new method and with Hassel and Farman's classification.

Table 4 Comparison of correlation of the different methods of assessment of vertebral maturation with the hand-wrist maturation.

	Methods compared	Correlation with wrist assessment	P
Males	Method proposed	0.79	NS
	Hassel and Farman	0.77	
	Method proposed	0.79	<0.001
	Lamparski	0.69	
	Hassel and Farman	0.77	<0.01
	Lamparski	0.69	
Females	Method proposed	0.85	NS
	Hassel and Farman	0.84	
	Method proposed	0.85	<0.01
	Lamparski	0.79	
	Hassel and Farman	0.84	<0.05
	Lamparski	0.79	

Discussion

The hand-wrist radiograph has been used classically to determine the level of maturation of a child. A good correlation was found both in the present study and by previous authors (Lamparski, 1972; Sato, 1987; O'Reilly and Yainiello, 1988; Caltabiano *et al*., 1990; Vilar *et al*., 1994; Hassel and Farman, 1995; Garcia-Fernandez *et al*., 1998) between this method and skeletal maturation of the cervical vertebrae. The new method was investigated to determine the maturation of a child without a hand-wrist radiograph to avoid extra radiation.

The correlation obtained in this investigation between the hand-wrist method and Lamparski's classification of cervical vertebrae maturation is lower than that reported by Lamparski (1972). This can be explained by the different ages of the patients. In his study, only children between 10 and 15 years old were included. However, many children, mainly males, still have growth potential at 15 years of age, and Hellsing (1991) demonstrated differences between 15-year-old and adult males in the height and size of the vertebral bodies.

Regarding gender, the results of the present investigation are in agreement with those of Lamparski (1972) and Caltabiano *et al*. (1990), who suggest that this method is more reliable in females than males. Caltabiano *et al*. (1990) found a somewhat lower correlation between hand-wrist and vertebral maturation, probably related to a different method of evaluation of hand-wrist maturation, which included the assessment of the carpal bones. The present study confirms in both genders the results of Vilar *et al*. (1994) with the Lamparski classification in a Spanish population that excluded men.

The results using Hassel and Farman's (1995) classification confirm its usefulness as reported by these authors. However, Hassel and Farman did not distinguish between males and females.

When the classifications of Hassel and Farman, and Lamparski were compared, a higher correlation with the hand-wrist maturation stages was found using Hassel and Farman's method. Two issues can account for this. First, the Hassel and Farman classification includes a more detailed description of every stage and, secondly, as previously stated, the Lamparski classification is incomplete due to the age of the sample.

A new simple method to evaluate skeletal maturation taking into account morphological characteristics of the cervical vertebrae was devised. The anatomical parameters considered were concavity of the lower border and height and shape of the vertebral bodies.

Concavity was demonstrated to be the best of the three parameters. Some authors have emphasized the importance of this parameter and it has been used in the classifications of vertebral maturation (Lamparski, 1972; Hassel and Farman, 1995). In this study, it was found that the greater maturation the higher was the concavity. The correlation between the hand-wrist maturation method and concavity was similar to that obtained when Hassel and Farman's classification was used, but higher than Lamparski's classification. Therefore, concavity assessment is as accurate as the Hassel and Farman classification, and better than Lamparski's classification to assess skeletal maturation.

The finding that the height of the vertebral bodies had a lower correlation with the hand-wrist radiograph than concavity can be explained by several factors. External agents such as pressure (Gooding and Neuhauser, 1965), corporal position (Taylor, 1975; Bridges, 1994), or disease (Bick and Copel, 1950; Hensinger, 1991; Bridges, 1994; Vastardis and Evans, 1996) can influence the height of vertebral bodies. In addition, the facial pattern can modify the height of the cervical vertebrae (Bench, 1963).

The shape of the vertebral bodies has been extensively studied (Bick and Copel, 1951; Bayley, 1952; Catell and Filtzer, 1965; Lamparski, 1972; Hassel and Farman, 1995). It has been found that shape changes with maturation. In the first stages of maturation the vertebral bodies are wedge-shaped with the superior vertebral borders tapered posterior to anterior. With growth the vertebral bodies become rectangular shaped, square shaped, and lastly rectangular with height greater than width.

The main strength of the present work is that with the three morphological variables an equation to accurately estimate the maturation stage of the wrist has been designed. The results show that the new method is comparable to those usually used in practice. The clinical implications of this approach must be emphasized. Firstly, the stage of the growth curve of a patient can be assessed by studying the cervical vertebrae, and secondly, the morphological parameters are separately evaluated; thus, it is simpler for the operator to determine the stage of every patient than when all parameters are considered together.

Conclusions

A new simple method based on morphological characteristics of the cervical vertebral bodies that can be used instead of the hand-wrist radiograph to evaluate the maturation stage has been designed. In the population investigated this method is as accurate as the Hassel and Farman classification and is superior to Lamparski's classification. The Hassel and Farman classification can be used to estimate the maturation stage in both males and females whilst the Lamparski classification is not sufficiently accurate in males and can be used only in females.

The best morphological vertebral parameter to estimate maturation is the concavity of the lower border of the body. It can also replace the wrist radiograph in the assessment of the maturation stage.

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