Original Article

Influence of skeletal class in the morphology of cervical vertebrae: *A study using cone beam computed tomography*

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ABSTRACT

Objectives: To quantify the prevalence of cervical vertebrae anomalies and to analyze any association between them and skeletal malocclusions or head posture positions in the same study.

Materials and Methods: Two hundred forty patients who were attending the Department of Orthodontics of the University of Valencia for orthodontic treatment were selected and divided into three groups: skeletal Class I (control group, $0° < \text{ANB} < 4°$), Class II ($\text{ANB} \geq 4°$), and Class III ($\text{ANB} \leq 0°$) according to ANB Steiner angle. The morphology of the first five cervical vertebrae was analyzed with cone beam computed tomography to identify any anomalies. Intra- and interobserver error methods were calculated.

Results: Dehiscence and fusion of one unit (both 23.3%) and partial cleft (11.7%) were the most frequent anomalies, while occipitalization was the least common (3.3%). Dehiscence anomaly was observed when the control group was compared with Classes II and III and partial cleft anomaly when Class I was compared with Class III. Furthermore, NSBa and ss-N-sm/ANB angles were associated with partial cleft anomaly, while NSL/NL angle and extended head posture were associated with fusion anomaly.

Conclusions: Fusion, dehiscence, and partial cleft were the most frequent cervical vertebrae anomalies. Dehiscence and partial cleft were found to present statistically significant differences between Class I and Classes II and III. Cervical vertebrae anomalies and head posture were associated with fusion. (*Angle Orthod.* 2017;87:131–137)

KEY WORDS: Head posture; Cervical vertebrae anomaly; CBCT; Skeletal class

INTRODUCTION

Cervical vertebrae analysis has been a useful aid to orthodontic diagnosis for several clinical implications. First, cervical vertebrae indicates skeletal age estimation, an important information for treating some types of malocclusion.[1,2] Malocclusion is thought to be the outcome of multiple influences deriving from genetic, postural, and environmental factors, especially the activity and posture of oral soft tissues.[3] Different anomalies of cervical vertebrae (fusions and posterior arch deficiency) have been reported to occur in patients with different malocclusions.[4] Traditionally, cervical vertebrae anomalies have been observed in patients with cleft lip and palate[5,6] or other craniofacial syndromes.[7] But some research into patients with no syndromes has affirmed that there is a high prevalence of these anomalies, particularly fusion between cervical vertebrae in skeletal Class II and III patients, due to a failure of normal embryologic segmentation.[8] Analysis of the relationship between cervical vertebrae anomalies and cranial morphology points to a relationship between the cervical vertebrae and jaws through the skull base.[9–12] This type of cranial morphology can be related to skeletal malocclusions.[13,14]

Previous studies have found skeletal Class III patients to have a prevalence of 61.4% of fusion vertebrae anomalies, while Class II patients have a prevalence of 28%.[13,15] In the vertical plane, some authors[11,16] have reported that in open bite patients, 42.1% presented cervical fusion and 13.2% posterior arch deficiency.

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Head and neck posture is another influential factor in craniofacial morphology, whereby an extended head posture in relation to the cervical vertebral column is associated with reduced sagittal jaw dimensions.[9–12,17] Some authors[14,18,19] have reported an association between higher head posture angles and patients with retrognathic jaws. Likewise, other authors[15,16] found an association between fusion anomalies and extension of the head with horizontal maxillary overjet.

Traditionally, studies examining cervical vertebrae anomalies have used lateral cephalograms as a measurement method[9–12,20–22] or even direct observation on autopsy material.[23] But these methods suffer limitations that can generate false-positive findings, preventing reliable diagnosis.[4,24] Lateral cephalograms have other limitations such as distortion, magnification, superposition of the right and left structures as well as difficulty in identifying and registering anatomical structures.[25]

Some research reports the evolution of two-dimensional (2D) radiography to three-dimensional (3D) cone beam computed tomography (CBCT) as a reliable and reproducible method that could replace lateral cephalograms for analyzing cervical vertebrae, allowing more accurate diagnosis and better location of morphologic deviations in the cervical vertebrae column.[4,6,21,26,27] While just two studies[6,26] have made use of CT, another three studies[25,27,28] are the only studies that have made this kind of analysis using CBCTs but only in skeletal Class II patients alone. CBCT is a widespread diagnostic tool in orthodontic patients (agenesis, supernumerary teeth, inclusion teeth, third molar surgery, orthognathic surgery, etc) that makes cervical column morphology exploration very easy.

To date, no other study has examined cervical vertebrae anomalies in skeletal Class I, II, and III malocclusions together in a single CBCT study with a sizeable patient sample. Therefore, the aims of this study were (1) to quantify the prevalence of cervical vertebrae anomalies and (2) analyze associations between them and skeletal malocclusions or head posture position measured with CBCT.

MATERIALS AND METHODS

This study was approved by the Ethics Committee for Research Involving Humans at the University (H1393231238425). Rights have been protected by an appropriate Institutional Review Board and informed consent to take part was granted by all subjects in writing. This cross-sectional observational human study was designed following the Declaration of Helsinki and STROBE guidelines.

Patients

Two hundred ninety-nine patients who were attending the Department of Orthodontics of the University of Valencia were randomly selected between February 2014 and May 2015. Power analysis showed that a sample size of at least 250 patients would provide a 90% probability of detecting a real odds ratio of 1.75 for the association between an independent factor (class or facial dimension) and presence of physical anomaly using a logistic regression model with a confidence level of 95%.

Inclusion criteria were patients with permanent dentition whose records included a CBCT for reasons unrelated to the concerns of this study (implants, third molar surgery, etc) and clearly displayed the first five cervical vertebrae and patients with Spanish ethnic background (being Spain as the country of birth for patients and both parents). Exclusion criteria were presence of any kind of traumatic accident in the past or scoliosis.

Fifty-nine patients were excluded from the final assessment as a result of applying inclusion and exclusion criteria. The final sample included 240 patients: 136 women (56.7%) and 104 (43.3%) men. The mean age was of 31.5 $\pm$ 3.8 (26.7–35.5) years.

This sample was classified according to the ANB angle[29]: skeletal Class I (control group): $0° < \text{ANB} < 4°$ (96 patients; 58 women and 38 men, mean age 32.1 $\pm$ 2.4 years); Class II: ANB $\geq 4°$ (76; 40 women and 36 men, 31.9 $\pm$ 2.9 years); and Class III: ANB $\leq 0°$ (68; 38 women and 30 men, 31.7 $\pm$ 1.9 years).

METHOD

The CBCT used in this study was the Planmeca Promax 3D (Planmeca, Helsinki, Finland). All CBCTs were captured with a 200- $\times$ 190-mm field of view. The voxel size was 0.4 mm.

To standardize the position of the patients while scanning, CBCT images were taken with the head in its natural position and lips and tongue in resting position, using two planes as references: the Frankfurt plane (sagittal view) and the bipupilar plane (frontal view), both parallel to the floor. This method avoided measurement errors related to head posture (when the head is flexed or extended).

First, the InVivoDental (Anatomage, San Jose, Calif) program was used to visualize and analyze the first five cervical vertebrae on the CBCT images. Measurements were performed by a calibrated and experienced main observer. The 3D image reconstructions were obtained from digital imaging and communications in medicine files by direct volume rendering technique using the 3D tool. Cervical vertebrae characteristics were classified according to the method proposed by

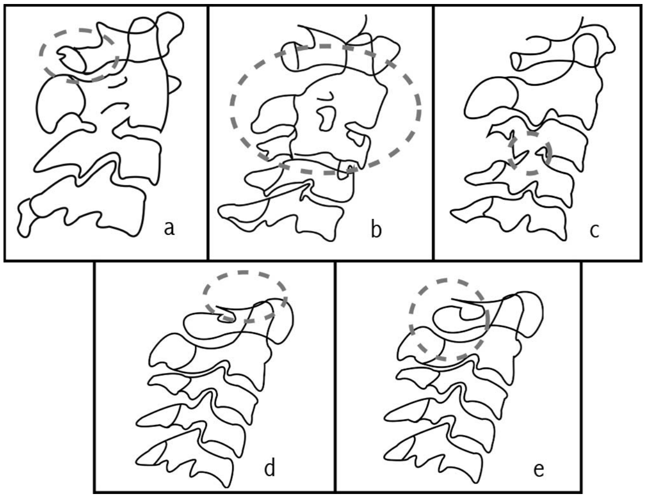

Figure 1. Cervical vertebrae anomalies: (a) dehiscence, (b) block fusion, (c) fusion, (d) occipitalization, and (e) partial cleft.

Sandham[5] and were divided into two categories (posterior arch deficiency and fusion anomalies) and four anomalies (partial cleft, dehiscence, fusion of one unit, and occipitalization; Figure 1; Table 1).

Second, and to analyze associations between craniofacial morphology and the posture of the head and the cervical column, lateral cephalograms were obtained from CBCT scans using the same software. Nineteen variables shown in Table 2 and Figure 2 described by Solow and Tallgren[14] were measured and analyzed in this study on these lateral cephalograms using the Dolphin Imaging Program (Dolphin Imaging & Management Solutions, Chatsworth, Calif). Nine angles measured head posture, two measured incisor relation, and eight angles measured craniofacial dimensions, including one cranial base angle, three vertical angles, and four sagittal angles.

Statistical Analysis

All statistical analyses were performed using a standard statistical software package (SPSS version 15.0, SPSS for Windows).

To assess interobserver error for the cervical vertebrae anomalies examination, a second observer established her own diagnosis (Kappa index). Second,

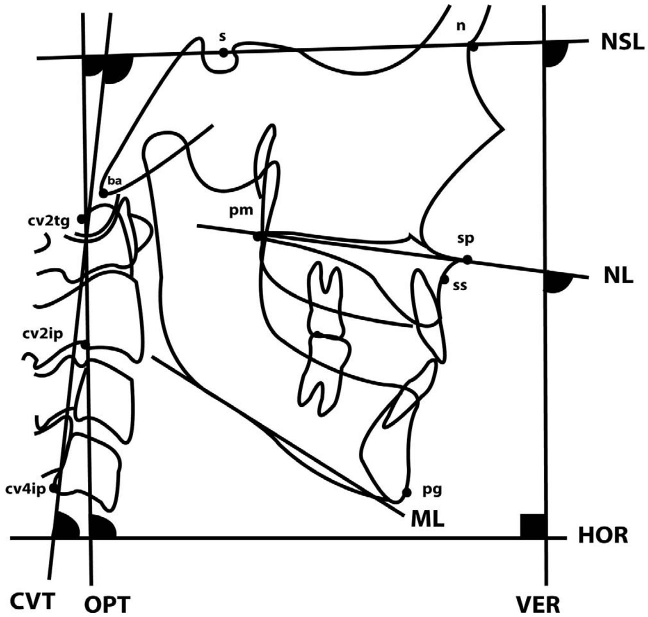

Figure 2. Linear and angular references by Solow and Tallgren.[14]

the reproducibility of all measurements was analyzed by determining intraobserver and interobserver measurement errors, calculated by the Dahlberg formula and coefficient of variation (CV%). To estimate intraobserver error, the main observer made a second set of measurements in a subsample of 30 CBCTs randomly selected after an interval of 1 week. To estimate reproducibility between observers (interobserver error), a previously trained and calibrated second observer performed the same measurements in the same 30 CBCTs.

For the previously described analysis of variance model, with a 5% significance level, and considering a size of 0.25 of the effect to detect, the power achieved was of 0.99 for the contrast of intrasubject effects and of 0.47 for intersubject effects.

Parametric tests (type-t) and nonparametric tests (Mann-Whitney) were applied to evaluate the homogeneity of averages and distributions of vertebrae anomalies.

Logistic regression analysis was used to identify the variables that explain the appearance of vertebral

Table 1. Definitions of Cervical Vertebrae Anomalies According to Sandham (1986)

Cervical Vertebrae Anomalies			Definition
Posterior arch deficiency	1	Partial cleft	Lack of fusion of posterior neural arch
	2	Dehiscence	Lack of development of part of the spinal unit
Fusion anomalies	3	Fusion of one unit	Fusion with another at the vertebral bodies, articulation facets, neural arch, or transverse processes
	4	Fusion block	Includes joining two or more vertebrae at the level of the vertebral bodies, facet joint, or neural arch transverse processes
	5	Occipitalization	Assimilation, either partially or completely, of the atlas (C1) with the occipital bone

Table 2. Head Posture, Craniofacial Dimensions, and Incisor Relation Measurements[a]

Measurements			
Head posture, °	1	NSL/VER	Nasion sella line: true vertical line
	2	NL/VER	Nasal line: true vertical line
	3	NSL/OPT	Nasion sella line: odontoid process tangent
	4	NL/OPT	Nasal line: odontoid process tangent
	5	NSL/CVT	Nasion sella line: cervical vertebrae tangent
	6	NL/CVT	Nasal line: cervical vertebrae tangent
	7	OPT/HOR	Odontoid process tangent: true horizontal
	8	CVT/HOR	Cervical vertebrae tangent: true horizontal line
	9	OPT/CVT	Odontoid process tangent: cervical vertebrae tangent
Craniofacial dimensions			
Sagittal dimensions, °	10	ss–N– Pg	Subspinale-nasion-pogonion
	11	ss–N–sm/ANB	Subspinale-nasion-supramentale
	12	S–N–ss	Sella-nasion-subspinale
	13	S–N–Pg	Sella-nasion-pogonion
Vertical dimensions, °	14	NL–ML	Nasal line–mandibular line
	15	NSL–NL	Nasion sella line–nasal line
	16	NSL–ML	Nasion sella line–mandibular line
Cranial base angle, °	17	N–S–Ba	Nasion-sellar-basion
Incisor relation, mm	18	Overjet	Distance between the maxillary anterior teeth and the mandibular anterior teeth in the anterior-posterior axis
	19	Overbite	Overlap of the maxillary central incisors over the mandibular central incisors

[a] Reference points and lines are defined according to Solow and Tallgren (1976).

anomalies. Estimates of the coefficients and odds ratios were obtained, with confidence intervals at 95%. Associations between the morphology of the cervical column and each craniofacial dimension were expressed in terms of the Nagelkerke logistic regression correlation coefficients (R^2) ($R = \sqrt{R^2}$) and tested for the possible effect of age and sex by multiple logistic regression analyses.

RESULTS

Intra- and Interobserver Errors

A Kappa index was calculated for interobserver error of cervical vertebrae anomaly examination (Kappa = 0.935), obtaining high correlation between the two observers.

Intra- and interobserver errors for all measurements are shown in Table 3. Regarding intraobserver error, Dahlberg d values obtained less than 1 mm for all measurements except S-N-Pg and NL/OPT; the highest CV was 1.59%. As for interobserver error, Dahlberg d values obtained less than 1 mm for ss-N-Pg, ss-N-sm/ANB, NSL/CVT, NL/CVT, overjet, and overbite. For the magnitude of the objects measured, the relative error ranged between 0.92% and 2.01%. Other measurements resulted in Dahlberg d values of less than 2.01 mm, with a relative error range between 0.76% and 2.41%.

Cervical Vertebrae Anomalies Prevalence

Figure 3 shows the distribution of prevalence of cervical vertebrae anomalies. Dehiscence and fusion of one unit (both 23.3%) and partial cleft (11.7%) were the most frequent anomalies, while occipitalization was the least common (3.3%); no block fusion was found.

Cervical Vertebrae Anomalies According to Skeletal Class

Figure 4 and Table 4 show the distribution of cervical vertebrae anomalies among skeletal classes. Mann-Whitney tests showed whether the distribution of

Table 3. Intra- and Interobserver Measurement Errors, Calculated by d Dahlberg's Formula and Coefficient of Variation (CV%)

		d Dahlberg, mm		CV %	
	Error	Intra-observer	Intero-bserver	Intra-observer	Inter-observer
1	NSL/VER	0.96	1.34	1.02	1.83
2	NL/VER	0.83	1.62	0.76	1.13
3	NSL/OPT	0.65	1.01	0.92	0.99
4	NL/OPT	1.03	1.12	1.28	1.77
5	NSL/CVT	0.45	0.42	0.79	1.22
6	NL/CVT	0.86	0.97	0.83	1.76
7	OPT/HOR	0.97	1.51	1.33	1.45
8	CVT/HOR	0.98	1.36	1.44	2.41
9	OPT/CVT	0.78	1.12	1.25	1.77
10	ss-N-Pg	0.90	0.91	1.11	2.01
11	ss-N-sm/ANB	0.32	0.94	0.81	0.92
12	S-N-ss	0.87	1.12	0.67	0.77
13	S-N-Pg	1.59	2.01	1.35	1.43
14	NL-ML	0.68	1.61	0.62	1.22
15	NSL-NL	0.54	1.21	1.20	1.26
16	NSL-ML	0.71	1.38	1.19	2.26
17	N-S-Ba	0.74	1.30	0.56	0.76
18	Overjet	0.18	0.68	1.59	1.74
19	Overbite	0.32	0.94	1.31	1.55

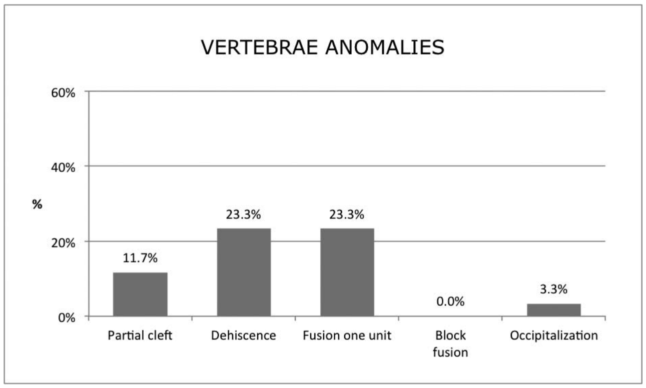

Figure 3. Vertebrae anomalies distribution.

anomalies was homogeneous between skeletal classes (groups) and *P* values. There were statistically significant relations between skeletal classes (groups) for the anomalies of partial cleft and dehiscence when comparing the control group (skeletal Class I) with skeletal Classes II and for dehiscence when comparing the control group with skeletal Class III.

Cervical Vertebrae Anomalies According to Craniofacial Dimensions and Incisor Relation Measurements

Table 5 shows the results of homogeneity testing for the relation between cervical vertebrae anomalies and craniofacial dimensions and incisor relation measurements. Significant relations were found between N-S-Ba and ss-N-sm/ANB and partial cleft anomaly (means 133.7° and 4.3° in presence compared with 131.9° and 1.2° in absence) and between NSL/NL and fusion anomaly (mean 6.3° in presence to 8.3° in absence), while no significant relations were found for dehiscence anomaly. Fusion block and occipitalization have been eliminated from this table since very few patients presented occipitalization and none presented block fusion.

Cervical Vertebrae Anomalies According to Head Posture

Table 6 shows the relationship between cervical vertebrae anomalies and head posture. NSL/VER, NSL/OPT, and CVT/HOR angles were significantly associated with fusion anomaly, while no significant relations were found for the rest of the angles. Fusion block and occipitalization have been eliminated from this table, as in Table 5.

DISCUSSION

Intraobserver error was found to be very good while interobserver error increased in a logical manner but pointed to high reproducibility. These results match those of Sonnesen et al.[30] According to the available literature, no other study has calculated these errors.

Regarding the prevalence of cervical vertebrae anomalies, dehiscence, fusion of one unit, and partial cleft were the most frequent anomalies in the sample. Similarly, Arntsen and Sonnesen[15] found that fusion was the most frequent anomaly but only among Class II patients. No block fusion anomalies occurred in the present sample, as in others.[4]

As for cervical vertebrae anomaly type in relation to skeletal class, significant relations were observed for dehiscence anomaly when comparing the control group with skeletal Class II and III and also for partial cleft anomaly when comparing the control group with Class II. As reported by other authors, no significant relations were found for fusion anomaly.[9,12] The higher prevalence of these anomalies in these skeletal malocclusion groups remains unexplained, but the cause might be found in early embryogenesis.[15] Associations between

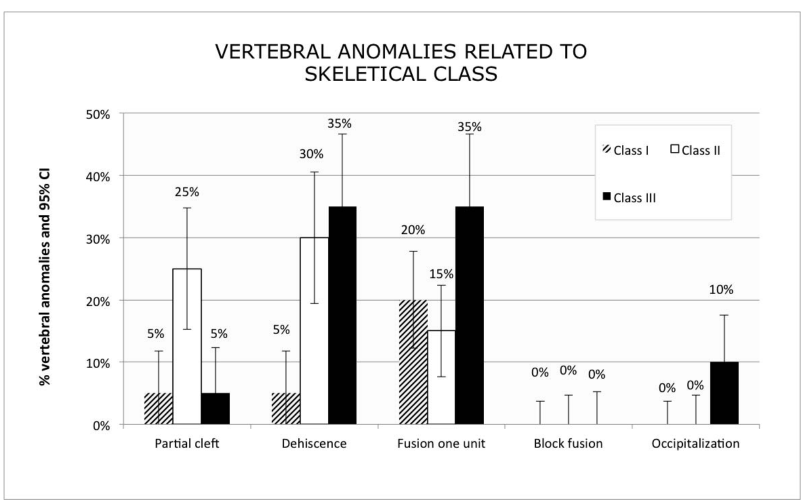

Figure 4. Vertebrae anomalies related to skeletal class.

Table 4. Homogeneity Test Group of Vertebral Anomalies Related to Skeletal Class[a]

Cervical Vertebrae Anomalies	Skeletal Class, Mann-Whitney (MW) and *P*-Valor (Test)	
	Class I and II (n = 96; n = 76)	Class I and III (n = 96; n = 68)
Partial cleft	(n = 5; n = 19) *P* = .049*	(n = 5; n = 3) *P* = 1.000
Dehiscence	(n = 5; n = 23) *P* = .040*	(n = 5; n = 24) *P* = .019*
Fusion of one unit	(n = 19; n = 11) *P* = .681	(n = 19; n = 24) *P* = .294
Fusion block	(n = 0; n = 0) *P* = 1.000	(n = 0; n = 0) *P* = 1.000
Occipitalization	(n = 0; n = 0) *P* = 1.000	(n = 0; n = 7) *P* = .152

[a] Number of cases (n) with anomaly per class group, Mann-Whitney (MW) tests and *P* values.
* $P < .05$.

craniofacial morphology in the vertical dimension and malocclusions have not been studied in this investigation, which is a limitation of this study.

Analyzing craniofacial measurements, cranial base angle and sagittal dimensions showed significant relations with partial cleft anomaly and NSL/NL angle with fusion anomaly. Craniofacial dimensions were related to cervical column morphology and posture. An extended head posture was associated with a large cranial base angle, large vertical craniofacial dimensions, and retrognathia of the jaws. This agrees with previous studies that have found that an extended head posture in relation to the cervical vertebral column is associated with increased vertical craniofacial dimensions and reduced sagittal jaw dimensions.[16]

Higher maxillary rotation and mandibular retrognathism were seen in subjects with fusion in our study, similar to the results of other studies.[12,31]

Explanations for the differing prevalence of fusions reported in the literature may include interpopulation diversity, differences in methodological reliability, subjectivity, and lack of interobserver calibration.[4,21] It is clear that samples can differ in age and that older subjects have larger cervical vertebrae anomalies, and thus more overlapping in conventional cephalograms, which might produce different outcomes from the present study, which used CBCT. Nevertheless, fusions should be already visible in children as they occur at a very early stage (embryologic development).[5,8]

Several studies have identified associations between head posture and cervical vertebrae anomalies.[14,18,19] In the present study, relations between extension of the head and cervical vertebrae anomalies were found for fusion anomaly in NSL/VER, NSL/OPT, and NSL/CVT angles as in other studies.

Because of the limitations of 2D lateral cephalograms (such as distortion, magnification, superposition of the right and left structures, and difficulty of identifying and registering anatomical structures),[6,21,24–26] the present study chose CBCT to evaluate vertebral anomalies, as in two previous studies.[25,27] All of them formed part of the patients' dental records and had been taken for other purposes rather than specifically for the study.

It is important to take advantage of all the diagnostic resources involved in orthodontic diagnosis. Whenever a CBCT is included in a patient's diagnostic records, the craniovertebral relationship should be taken into account. Cervical vertebrae anomalies could be a sign of a skeletal malocclusion and must be analyzed as an additional element of orthodontic diagnosis.

Table 5. Homogeneity Test Group of Craniofacial Dimensions and Incisor Relation With Cervical Vertebrae Anomalies[a]

Craniofacial Dimensions and Incisor Relation		Cervical Vertebrae Anomalies, Mann-Whitney (MW) and *P*-Valor (Test)		
		Partial Cleft (n = 28)	Dehiscence (n = 56)	Fusion One Unit (n = 56)
1	ss-N-Pg	.055	.779	.325
2	ss-N-sm/ANB	.046*	.840	.466
3	S-N-ss	.752	.370	.533
4	S-N-Pg	.287	.272	.246
5	NL-ML	.276	.854	.217
6	NSL-NL	.822	.087	.049*
7	NSL-ML	.256	.331	.993
8	N-S-Ba	.002**	.979	.623
9	Overjet	.718	.426	.694
10	Overbite	.946	.411	.766

[a] Number of cases with anomaly (n), *P* values from Mann-Whitney (MW) test.
* $P < .05$; ** $P < .01$.

Table 6. Homogeneity Test of Cervical Vertebrae Anomalies and Head Posture[a]

		Cervical Vertebrae Anomalies, Mann-Whitney (MW) and *P*-Valor (Test)		
		Partial Cleft (n = 28)	Dehiscence (n = 56)	Fusion One Unit (n = 56)
1	NSL/VER	.604	.766	.636
2	NL/VER	.402	.081	.047*
3	NSL/OPT	.946	.903	.012*
4	NL/OPT	.910	.323	.637
5	NSL/CVT	.804	.847	.713
6	NL/CVT	.752	.759	.854
7	OPT/HOR	.964	.958	.372
8	CVT/HOR	.893	.529	.025*
9	OPT/CVT	.774	.071	.125

[a] Number of cases with anomaly (n), *P* values from Mann-Whitney (MW) test.
* $P < .05$.

CONCLUSIONS

- Fusion, dehiscence, and partial cleft were the most frequent cervical vertebrae anomalies.
- There were statistically significant relations between skeletal classes for the anomalies of partial cleft and dehiscence when comparing Class I and II and for dehiscence when comparing Class I and III.
- Cervical vertebrae anomalies and head posture were associated with fusion.

REFERENCES

1. Hassel B, Farman AG. Skeletal maturation evaluation using cervical vertebrae. *Am J Orthod Dent Orthop*. 1995;107:58–66.
2. 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.
3. Mew J. The postural basis of malocclusion: a philosophical overview. *Am J Orthod Dentofacial Orthop*. 2004;126:729–738.
4. Bebnowski D, Hänggi MP, Markic G, Roos M, Peltomäki T. Cervical vertebrae anomalies in subjects with Class II malocclusion assessed by lateral cephalogram and cone beam computed tomography. *Eur J Orthod*. 2012;34(2):226–231.
5. Sandham A. Cervical vertebral anomalies in cleft-lip and palate. *Cleft Palate J*. 1986;23:206–214.
6. Rajion ZA, Townsend GC, Netherway DJ, Anderson PJ, Yusof A, Hughes T. A three-dimensional computed tomographic analysis of the cervical spine in unoperated infants with cleft lip and palate. *Cleft Palate Craniofac J*. 2006;43:513–518.
7. Samartzis DD, Herman J, Lubicky JP, Shen FH. Classification of congenitally fused cervical patterns in Klippel-Feil patients: epidemiology and role in the development of cervical spine-related symptoms. *Spine*. 2006;31:e798–e804.
8. Yochum TR, Rowe LJ. *Essentials of Skeletal Radiology*. Baltimore, Md: Lippincott Williams & Wilkins; 2005.
9. Sonnesen L, Kjaer I. Cervical column morphology in patients with skeletal Class III malocclusion and mandibular overjet. *Am J Orthod Dentofacial Orthop*. 2007;132:427.e7–12.
10. Sonnesen L, Kjaer I. Cervical vertebral body fusions in patients with skeletal deep bite. *Eur J Orthod*. 2007;29:464–470.
11. Sonnesen L, Kjaer I. Cervical column morphology in patients with skeletal open bite. *Orthod Craniofac Res*. 2008;11:17–23.
12. Sonnesen L, Kjaer I. Anomalies of the cervical vertebrae in patients with skeletal Class II malocclusion and horizontal maxillary overjet. *Am J Orthod Dentofacial Orthop*. 2008;133:188.e15–20.
13. Vastardis H, Evans CA. Evaluation of cervical spine abnormalities on cephalometric radiographs. *Am J Orthod Dentofacial Orthop*. 1996;109:581–588.
14. Solow B, Tallgren A. Head posture and craniofacial morphology. *Am J Phys Anthropol*. 1976;44:417–435.
15. Arntsen T, Sonnesen L. Cervical vertebral column morphology related to craniofacial morphology and head posture in preorthodontic children with Class II malocclusion and horizontal maxillary overjet. *Am J Orthod Dentofacial Orthop*. 2011;140:e1–7.
16. Kim P, MT Sarauw, Sonnesen L. Cervical vertebral column morphology and head posture in preorthodontic patients with anterior open bite. *Am J Orthod Dentofacial Orthop*. 2014;145:359–366.
17. Sonnesen L, Pedersen CE, Kjaer I. Cervical column morphology related to head posture, cranial base angle, and condylar malformation. *Eur J Orthod*. 2007;29:398–403.
18. Huggare JA, Raustia AM. Head posture and cervicovertebral and craniofacial morphology in patients with craniomandibular dysfunction. *Cranio*. 1992;10:173–177.
19. Huggare J. Postural disorders and dentofacial morphology. *Acta Odontol Scand*. 1998;56:383–386.
20. Lima MC, Franco EJ, Janson G, Carvalho IM, Santos CF, Capelozza AL. Prevalence of upper cervical vertebrae anomalies in patients with cleft lip and/or palate and non cleft patients. *Cleft Palate Craniofac J*. 2009;46:481–486.
21. Koletsis DD, Halazonetis DJ. Cervical vertebrae anomalies in orthodontic patients: a growth-based superimpositional approach. *Eur J Orthod*. 2009;32:36–42.
22. Ríos-Rodenas M, de Nova J, Gutiérrez-Díez MP, et al. A cephalometric method to diagnosis the craniovertebral junction abnormalities in osteogenesis imperfecta patients. *J Clin Exp Dent*. 2015;7(1):e153–e158.
23. Templeto AW, Brown MW. The transverse processes of the cervical vertebral segment: a correlation of oblique roentgenograms with skeletonized material. *Radiology*. 1964;82:912–915.
24. Patcas R, Tausch D, Pandis N, et al. Illusions of fusions: assessing cervical vertebral fusion on lateral cephalograms, multidetector computed tomographs, and cone-beam computed tomographs. *Am J Orthod Dentofacial Orthop*. 2013;143:213–220.
25. Bedoya A, Landa Nieto Z, Zuluaga LL, Rocabado M. Morphometry of the cranial base and the cranial-cervical-mandibular system in young patients with type II, division 1 malocclusion, using tomographic cone beam. *Cranio*. 2014;32:199–207.
26. Carreon LY, Djurasovic M, Glassman SD, Sailer P. Diagnostic accuracy and reliability of fine-cut CT scans with reconstructions to determine the status of an instrumented posterolateral fusion with surgical exploration as reference standard. *Spine*. 2007;32:892–895.
27. Shi H, Scarfe WC, Farman AG. Three-dimensional reconstruction of individual cervical vertebrae from cone-beam computed-tomography images. *Am J Orthod Dentofacial Orthop*. 2007;131:426–432.
28. Popat H, Drage N, Durning P. Mid-line clefts of the cervical vertebrae: an incidental finding arising from cone beam computed tomography of the dental patient. *Br Dent J*. 2008;204:303–306.
29. Steiner CC. Cephalometrics for you and me. *Am J Orthod*. 1953;39:729.
30. Sonnesen L, Jensen KE, Petersson AR, Petri N, Berg S, Svanholt P. Cervical vertebral column morphology in patients with obstructive sleep apnea assessed using lateral cephalograms and cone beam CT: a comparative study. *Dentomaxillofac Radiol*. 2013;42(6):20130060.
31. Björk, A. Cranial base development. *Am J Orthod*. 1995;41:198–225.