ORIGINAL RESEARCH

Craniocervical posture and skeletal relationship in Peruvian adolescents

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Abstract

Background: Active skeletal growth occurs during adolescence. Elucidating cervical and craniofacial biomechanical connection can help to understand causal relationships and improve orthodontic diagnosis and treatment. This study aimed to evaluate the association between craniocervical posture (CP) versus the sagittal and vertical skeletal relationship (SR) in Peruvian adolescents. **Methods**: This retrospective study evaluated 153 digital lateral radiographs of adolescents (72 males and 81 females) aged 13 to 17 years (mean age 15.22 ± 1.52 years) distributed into nine groups according to the sagittal SR based on the point A–nasion line to point B–nasion line (ANB) angle (class I, II, and III) and vertical SR according to the nasion-sella line and the occlusal plane (NSL-OP') angle (normodivergent, hypodivergent, and hyperdivergent). CP was analyzed using the Solow and Rocabado parameters. Multiple linear regression models were used to determine the association of CP and SR considering $p < 0.05$. **Results**: The sagittal and vertical SR groups showed associations with multiple parameters of CP ($p \leq 0.037$). For nine CP parameters, a trend toward cervical flexion was observed in Class III adolescents and toward cervical extension in Class II adolescents across different vertical SR. In model 2, six CP parameters showed significant correlations with the ANB angle ($R^2 = 33.3\%$, $p < 0.001$) and the NSL-OP' angle ($R^2 = 61.8\%$, $p < 0.001$). **Conclusions**: Craniocervical posture parameters were found to be associated with sagittal skeletal relationships. A tendency to the more extended CP was associated with a class II ANB angle, while CP was more flexed in class III regardless of vertical growth. Healthcare professionals should consider cervical posture in the multidisciplinary management of orthodontic treatment for adolescents.

Keywords

Adolescent; Cervical; Posteroanterior cephalometry; Posture

1. Introduction

There is growing interest in knowledge regarding the biomechanical relationship of the maxillary bones and the position of the skull and neck. These systems act as a unit due to the anatomical proximity of their components that interact in static and dynamic positions [1]. Any impairment related to these areas is of diagnostic value to dentists and physical rehabilitators. Indeed, postural imbalances due to lack of physical activity and the use of electronic devices are commonly found even in the young population [2, 3].

Malocclusion is a common oral health problem in adolescents and is prevalent in Latin America [4]. Anatomical interactions vary in regard to alteration of the jaw position. Inadequate posture or incorrect muscular position of the head and neck generates instability and contractions that unbalance the craniocervico-mandibular unit (CCMU), and thus, craniocervical posture (CP) is considered among the etiological factors of malocclusion [5].

Skeletal class refers to the skeletal relationship (SR) of the maxilla and mandible, the alteration of which involves skeletal malocclusion [6]. Dysfunction of the jaws at the base of the skull is associated with a series of factors, such as crowding and dental diastema, overbite, protrusion, altered molar relationship and midline displacement, among others [7], and is considered to be a causal factor in the disharmony of craniofacial bone growth [8].

The natural position of the head and CP are established by neuromuscular balance and physiological and environmental conditions. Proprioception is a key process in this stability [9, 10]. During human growth and development, these structures can influence the development of respiratory obstruction [11], temporomandibular disorder, and bruxism [12]. These factors influence functional health for orthodontic treatment and mandibular replacement in orthognathic surgery [13].

The impact of genetics and the environment on sagittal SR and CP has been extensively studied [13, 14], but their interrelationship has been less studied in regard to the aspects

of bone base inclination [15]. On one hand, previous studies have described a more widespread CP in class II and hyperdivergence and in class III and hypodivergence in children and adolescents in China [16–18] and Iran [19, 20], and children in Italy [21], Peru [22] and Serbia [23]. On the other hand, two studies conducted in children in Colombia [24] and children and adolescents in Turkey [25] found no relationship between posture and the SR (**Supplementary Table 1**, Ref. [16–25]).

The relation of SR and CP could be influenced by differences in the ethnic origin of individuals [17]. The Latin American population has a significant genetic mix. Peru, in particular has a predominance of indigenous native ancestry and a lower European and African contribution [26, 27]. Taking into account this continuous historical miscegenation, anatomical adaptation could have impacted the functionality of the CCMU [13, 17], making it necessary to study the population anthropometry in a specific geographic space [26].

Dentoskeletal problems are frequent in the young population [25], with many adolescents performing little physical activity and frequently using electronic devices that may affect CP [28, 29]. Correction of maxillary skeletal problems can be complemented with postural adjustments at early ages, and thus, clarification of this interrelationship would improve orthodontic diagnosis and planning [13, 14]. According to a systematic review, CP and malocclusions are interrelated and the authors recommended controlling for age due to the impact on natural growth changes [13]. Therefore, the purpose of the present study was to evaluate the association between CP and sagittal and vertical SR in a sample of Peruvian adolescents.

2. Materials and methods

2.1 Type of study and ethics

This cross-sectional analytical study was approved by the Institutional Committee of Research Ethics of the Universidad Científica del Sur (No. 264-CIEI-CIENTÍFICA-2022). The study was conducted according to the Strengthening the reporting of observational studies in epidemiology (STROBE) guideline and the principles set out in the Declaration of Helsinki. Informed consent was obtained for retrospective evaluation of the radiographic data of all the adolescent participants and their parents.

2.2 Selection of the sample

The study was made up of a convenience sample consisting of 153 digital lateral radiographs (DLR) of adolescents (72 males and 81 females), aged 13 to 17 years (mean age 15.22 ± 1.52 years). The DLR were obtained from two private radiological centers in Lima (Peru) between January 2022 and December 2023. Radiographies showing up to the fourth cervical vertebra of adolescents born in Peru were included in the study. Images compatible with craniocervical or facial malformation, surgical or orthodontic treatment or image distortion were excluded.

2.3 Sample size

The sample size was determined with the statistical program G*Power 3.1.9.732 (Heinrich Heine Universität Düsseldorf, Düsseldorf, NRW, Germany) based on a pilot study of 14 CP parameters in the 9 sagittal/vertical SR groups (n = 3 DLR per group). We considered the mixed effects interaction estimation formula with the size of the medium effect ($f = 0.361$; lowest value obtained with NL-OPT and FH-CVT), a confidence level of 95%, and a power of 80%. The result was 14 DLR per group, which was increased to 17 DLR to match the sample size of a previous study [25].

2.4 Imaging

The DLR were obtained using Orthophos SL 3D digital radiology equipment (Dentsply Sirona, Bensheim, HE, Germany) with a configuration of 84 kV, 13 mA and exposure time of 14.67 s, and Newtom Giano HR digital radiology equipment (NewTom, Cefla S.C., Imola, Italy), with a configuration of 60–90 kV, 1–10 mA and an exposure time 10.45 s. Patients were positioned in the cephalostat aligned with the nasion, with adjustment to the nasal bridge, and adjusting the ear rods symmetrically in the external auditory canals to stabilize and position the head. The radiography was taken with the patient's head positioned so that the Frankfort plane was parallel to the floor, corroborating the measurement with the preview before the final shot. Visualization of the radiographic images was performed using two software; Sidexis 4 v.4.3 (Dentsply Sirona, Bensheim, HE, Germany) for the Solow and Nemoceph v.6.0 analysis (Nemotec, Madrid, Spain) for the Steiner and Rocabado analysis.

2.5 Pilot study and calibration

The principal investigator was trained by a specialist in orthodontics and maxillary orthopedics and calibrated by a specialist in oral radiology, both with more than 10 years of work experience in their field. A pilot study was conducted in 15 cephalometries included in the study (10% of the sample). Calibration was analyzed with the intraclass correlation coefficient (ICC) of the linear or angular cephalometric measurement parameters that resulted in inter-examiner (ICC ≥ 0.798; substantial) and intra-examiner agreement with a two-week interval of reevaluation (ICC ≥ 0.908; almost perfect) interpreted according to the criteria of Landis and Koch.

2.6 Sagittal and vertical skeletal relationship

The SR was assessed according to Steiner's analysis (Fig. 1A). Sagittal cephalometries of the adolescents included were classified according to the angle formed by point A–nasion line to point B–nasion line (ANB), with class I ($0°–5°$), class II ($>5°$), and class III ($<0°$) (n = 51 per group) [16, 18, 20]. The vertical SR was determined by the angle of the nasion-sella line and the occlusal plane (NSL-OP') distributed into normodivergent ($10°–18°$), hyperdivergent ($>18°$), and hypodivergent ($<10°$) (n = 51 per group). The images were selected by convenience with quotas until 17 individuals were completed in each subsample of the nine groups of the sagittal/vertical SR (**Supplementary Fig. 1**). The sex and age of the groups are shown in **Supplementary Table 2**.

2.7 Parameters of craniocervical posture

CP was analyzed according to the cephalometric measurements proposed by Solow of 1976 (Fig. 1B) [16–21, 23–25] and Rocabado of 1983 (Fig. 1C) [22, 24]. A total of 14 parameters obtained from the identification of 17 points, 11 lines, 14 angles, and 2 distances were evaluated in the cephalometric analysis [9–12, 15, 17, 20, 25]. The Rocabado parameters evaluated were MGP-OP angulation (°) with rotation of posterior skull (<96°), average (96°–106°) and anterior (>106°), C0–C1 (mm) distance with decreased distance (<4 mm), average (4–9 mm) and increased (>9 mm), and H distance (mm) with high hyoid triangle position (<3 mm), average (3–7 mm) and low (>7 mm). The Solow parameters analyzed were the angles NSL-OPT, FH-OPT, NL-OPT, ML-OPT, NSL-CVT, FH-CVT, NL-CVT, ML-CVT, NSL-RL, FH-RL, and NL-RL. The definition of CP cephalometric measurements is described in Table 1.

2.8 Statistical analysis

The variables were described with means, standard deviation, frequencies and percentages. Normal distribution was assessed with the Kolmogorov-Smirnov (n > 50) or Shapiro-Wilk test (n ≤ 50). Inferential tests included analysis of variance (ANOVA) with the Tukey *post-hoc* test, Kruskal-Wallis with pair comparison, Pearson or Spearman correlation, and Chi-square. The correlation ranges were very low (<0.2), low (0.2–0.39), moderate (0.4–0.59), high (0.6–0.79), very high (0.8–0.99) and perfect (1). The association between CP and SR was assessed with multiple linear regression models to further explore the interrelationship of the variables. Since the sample was evaluated at the growth and development stage, the parameters of the CP were used as predictors of ANB and NSL-OP' angles. The homologous SR group (vertical and sagittal, respectively) was also considered a predictive factor because it did not affect the explanation of the models. A second model was selected and fitted based on a significant decrease in the Akaike Information Criterion (AIC) value (Δ9–13), with linearity assumptions verified using residual plots, no autocorrelation of residuals confirmed by the Durbin-Watson statistic (1.75–1.85), homoscedasticity confirmed by the Breusch-Pagan test ($p > 0.245$), normality of residuals confirmed by the Kolmogorov-Smirnov test ($p > 0.812$), no multicollinearity verified by the Variance Inflation Factor (1.04–4.59), and the absence of outliers confirmed by Cook's Distance (≤ 0.09). The performance of the models was analyzed using the coefficient of determination (R^2) and controlled for sex and age. Data was analyzed with the IBM-SPSS v.22.0 for Windows statistical software (IBM Corp., Armonk, NY, USA) and Jamovi v.2.3.24 (The Jamovi Project) at a significance level of 0.05.

3. Results

3.1 Sample characteristics

A total of 233 DLR were reviewed, excluding 80 DLR due to lack of visualization of the fourth cervical vertebra (n =
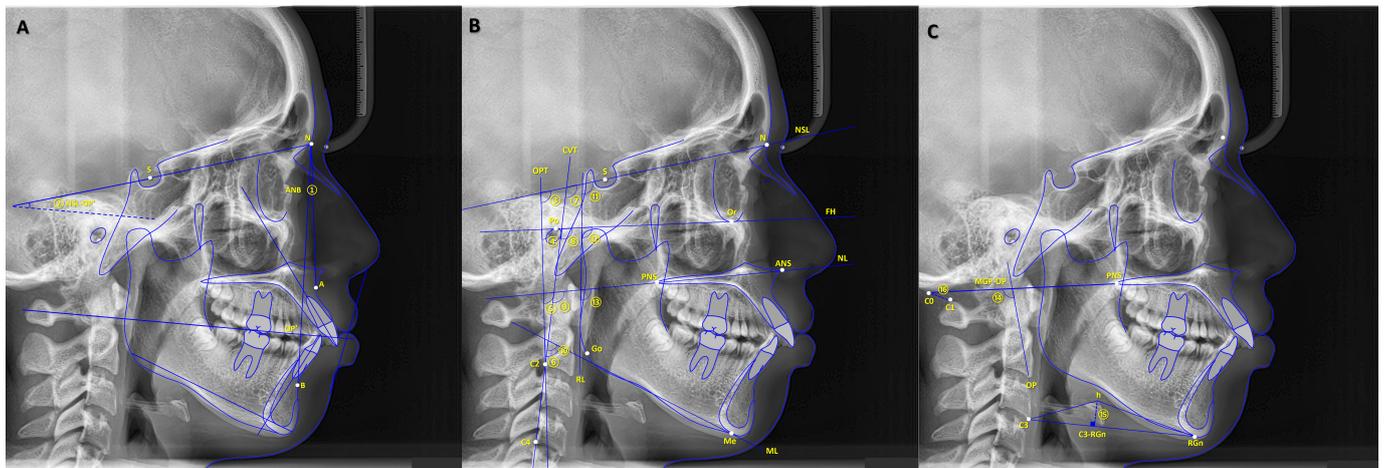

FIGURE 1. Reference points, lines and angles for measurements according to Steiner (Fig. 1A), Solow (Fig. 1B), and Rocabado (Fig. 1C): nasion (N), sella (S), subspinale (A), supramentale (B), occlusal plane (OP'), orbital (Or), porion (Po), anterior nasal spine (ANS), posterior nasal spine (PNS), mentonian (Me), gonion (Go), base of the occipital bone (C0), first vertebral cervical (C1), second cervical vertebra (C2), third cervical vertebra (C3), fourth cervical vertebra (C4), hyoid (h), retrognation (RGn), nasion–sella line (NSL), Frankfurt horizontal (FH), nasal line (NL), mandibular line (ML), odontoid process tangent (OPT), cervical vertebral tangent (CVT), ramus line (RL), McGregor plane (MGP), odontoid plane (OP). Parameters: ANB: point A–nasion line to point B–nasion line; NSL-OP': nasion–sella line to occlusal plane; NSL-OPT: nasion–sella line to odontoid process tangent; FH-OPT: Frankfurt horizontal to odontoid process tangent; NL-OPT: nasal line to odontoid process tangent; ML-OPT: mandibular line to odontoid process tangent; NSL-CVT: nasion–sella line to cervical vertebral tangent; FH-CVT: Frankfurt horizontal to cervical vertebral tangent; NL-CVT: nasal line to cervical vertebral tangent; ML-CVT: mandibular line to cervical vertebral tangent; NSL-RL: nasion–sella line to ramus line; FH-RL: Frankfurt horizontal to ramus line; NL-RL: nasal line to ramus line; MGP-OP: McGregor plane to odontoid plane; H: point "h" to C3-RGn line; C0–C1: distance from C0 to C1.

T A B L E 1. Points, lines, angles and cephalometric distances used.

Parameters	Definition
Points	
A	Subspinale. Posteroinferior point of the anterior concavity in the bony profile of the upper jaw
B	Supramentale. Posteroinferior point of the anterior concavity in the bony profile of the anterior border of the mandible
h	Hyoid. The anterosuperior point of the hyoid bone body
N	Nasion. The most anterosuperior point of the frontonasal suture
S	Sella. The most anterosuperior point located in the center of the sphenoid sella turcica
ANS	Anterior nasal spine. The most anterosuperior point of the spinous process of the upper jaw
PNS	Posterior nasal spine. The most posteroinferior point of the horizontal contour of the palatine bones
C0	Base of the occipital bone. The most posteroinferior point of the occipital bone
C1	First cervical vertebra. The most posterosuperior point of the posterior arch of the atlas
C2	Second cervical vertebra. The most posteroinferior point of the body of the second cervical vertebra
C3	Third cervical vertebra. The most anteriorinferior point of the body of the third cervical vertebra
C4	Fourth cervical vertebra. The most posteroinferior point of the body of the fourth cervical vertebra
Me	Mentonian. The most posteroinferior point of the contour of the mental symphysis
Go	Gonion. The most posteroinferior point of the mandible at the level of the vertex of the gonic angle
Or	Orbital. The most posteroinferior point of the orbital contour
Po	Porion. The most anterior superior point of the external auditory canal
RGn	Retrognation. The most posteroinferior point of the mandibular symphysis
Lines	
OP	Odontoid plane. Connecting the anteroinferior border of the axis body to the apex of the odontoid process
OP'	Occlusal plane. Bisector from the incisal edge of the upper incisors to the cusps of the first upper molars
MGP	McGregor plane. Connects the occipital base with the ENP
C3-RGn	Line formed by C3 and RGn
CVT	Cervical vertebral tangent. Tangent after line C2 to C4
FH	Frankfurt horizontal. Line through Or and Po
NL	Nasal line. Line through ANS and PNS
NSL	Nasion–sella line. Line of the dots N and S
ML	Mandibular line. Lower jaw edge line from Go to Me
OPT	Odontoid process tangent. Line tangent to the odontoid process passing through C2
RL	Ramus line. Tangent line to the posterior border of the mandibular ramus
Angles	
ANB	① Sagittal skeletal relationship. Angle formed by the lines N-A and N-B
NSL-OP'	② Vertical skeletal relationship. Angle formed between NSL and OP'
NSL-OPT	③ Craniocervical posture. Angle formed between NSL and OPT line
FH-OPT	④ Craniocervical posture. Angle formed between FH and OPT
NL-OPT	⑤ Craniocervical posture. Angle formed between NL and OPT
ML-OPT	⑥ Craniocervical posture. Angle formed between ML and OPT
NSL-CVT	⑦ Craniocervical posture. Angle formed between NSL and CVT
FH-CVT	⑧ Craniocervical posture. Angle formed between FH and CVT
NL-CVT	⑨ Craniocervical posture. Angle formed between NL and CVT
ML-CVT	⑩ Craniocervical posture. Angle formed between ML and CVT
NSL-RL	⑪ Rotation of the branch in relation to the skull. Angle formed between NSL and RL
FH-RL	⑫ Rotation of the branch in relation to the skull. Angle formed between FH and RL
NL-RL	⑬ Rotation of the branch in relation to the skull. Angle formed between NL and RL
MGP-OP	⑭ Head rotation. Angle formed between MGP and OP
Distances	
H	⑮ Vertical position of the hyoid. Perpendicular distance from point "h" to line C3-RGn
C0–C1	⑯ First suboccipital space. Distance formed between C0 and C1

30), craniocervical or facial malformation (n = 17), surgical or orthodontic treatment (n = 20), and image distortion (n = 13). The final sample included 153 DLR. Table 2 presents the characteristics of the study sample including sex, age, SR, and CP. A higher proportion of adolescents had average (45.1%) or anterior rotation (34.6%), increased C0–C1 distance (81%), and low hyoid bone position (69.9%). Most CP parameters were not related to sex or age. Male sex was positively associated with the C0–C1 angle and distance ($p = 0.011$ and 0.049, respectively) and triangle and hyoid position ($p < 0.001$), while age was positively correlated with the angle of the hyoid triangle ($p = 0.006$).

3.2 Comparison of craniocervical posture in different sagittal skeletal relationships

Table 3 shows the comparisons of CP and sagittal SR. Multiple parameters of the CP showed a very low negative correlation (MGP-OP) and a low positive correlation (NSL-CVT, FH-CVT, NL-CVT, ML-CVT, NSL-RL, FH-RL, and NL-RL) with the ANB angle ($p \leq 0.029$). A higher CP parameter was positively associated with SR with class I and III (MGP-OP), class I and class II (NSL-CVT, FH-CVT, and NL-CVT), class I (ML-CVT), class II (NSL-RL, FH-RL, and NL-RL) compared with the other skeletal class groups ($p \leq 0.022$). In summary, class II subjects consistently demonstrated more extended CP across multiple parameters, while class III subjects showed a more flexed posture.

3.3 Comparison of craniocervical posture in different vertical skeletal relationships

Table 4 presents the comparisons of CP and vertical SR. Some CP parameters showed a low positive (NSL-OPT and NSL-RL) and a low negative correlation (ML-OPT and ML-CVT) with the NSL-OP' angle ($p \leq 0.007$). A higher CP parameter result was positively associated with the vertical hyperdivergent compared with the hypodivergent SR (NSL-OPT), and the hypodivergent compared with the hyperdivergent (ML-OPT and ML-CVT) ($p \leq 0.049$). In general, most CP parameters showed no differences between the different vertical SRs.

3.4 Comparison of craniocervical posture in different sagittal/vertical skeletal relationships

Supplementary Table 3 shows that the sagittal and vertical SR groups had associations with multiple CP parameters (NSL-OPT, ML-OPT, NSL-CVT, FH-CVT, NL-CVT, ML-CVT, NSL-RL, FH-RL, and NL-RL) ($p \leq 0.037$). A trend towards significantly lower values was found in class III with a normodivergent vertical (NSL-OPT, NSL-RL, FH-RL, and NL-RL), hypodivergent (NSL-OPT, NSL-CVT, FH-CVT, ML-CVT, NSL-RL, FH-RL, and NL-RL), and hyperdivergent SR (ML-OPT, NSL-CVT, FH-CVT, NL-CVT, and ML-CVT) compared with the other vertical SR of classes II and class I. This indicates that, regardless of the vertical SR, multiple parameters were consistent with a more flexed CP in class III compared with other skeletal classes.

3.5 Predictors of sagittal/vertical skeletal relationship according to craniocervical posture

Supplementary Table 4 shows results of multiple linear regression analyses to associate CP and SR. All multiple linear regression models were significant ($p < 0.001$). The second model showed a moderate fit, explaining 33.3% of the variability in the ANB angle ($F = 7.82$, $p < 0.001$). ANB was positively associated with H, NSL-OPT, ML-CVT, and NSL-RL, and negatively associated with NSL-OP', MGP-OP, and ML-OPT. The second model showed a moderate fit, explaining 61.8% of the variability in the NSL-OP' angle ($F = 22.9$, $p < 0.001$). NSL-OP' was positively associated with NSL-OPT, ML-CVT, and NSL-RL, and negatively associated with ANB, ML-OPT, NSL-CVT, and NL-RL.

4. Discussion

Understanding the interrelationships of head-neck posture, skeletal features, and the facial biotype are important for diagnosis and treatment in orthodontics and maxillary orthopedics, as well as the functional health of individuals. The objective of this study was to evaluate CP by means of DLR using the standardized analyses of Rocabado and Solow, and to compare CP with the nine skeletal classes formed from the anteroposterior and craniocaudal analysis. The hypothesis of the study proved the existence of differences in CP according to sagittal and vertical SR in Peruvian adolescents, regardless of sex and age. Specifically, the results showed an extended posture in class II and a flexed posture in class III, which corroborated what was found in several previous studies of different adolescent populations [16–20, 23].

Regarding the CP parameters analyzed with Rocabado in a sample of adolescents aged 13 to 18 years, we found a higher frequency of average cranial rotation (45%), increased C0–C1 distance (81%), and lower hyoid bone position (69.9%), similar to a previous study in Peruvian children aged 6 to 12 years [22]. These last two parameters indicate a more forward CP among adolescents, who may spend prolonged amounts of time using technological equipment with screens in non-ergonomic positions at very low heights during their schoolwork [28, 29]. Bad CP can generate muscle pain and headaches even in young people, making it important for families to encourage physical activity and raise awareness and motivate children and adolescents to correct inappropriate posture [30].

In the present study, according to sex and age, the parameters of CP showed a significant association with two out of the 14 parameters analyzed. A more extended CP was associated with female adolescents (↓ C0–C1 and H) and with younger ages (↓ H). This could be due to the fact that women and younger individuals have a greater reduction in flexion capacity associated with muscle type compared with men and older individuals [21]. These results were corroborated in previous studies in which a more flexed head position was associated with Colombian boys (↑ MGP-OP and C1–C2) [24] and at older ages in Peruvian children (↑ H) [22]. This result is likely associated with the difference of height and weight

T A B L E 2. Maxillofacial and craniocervical posture parameters according to sex of the study sample.

Variables	Male (n = 72)		Female (n = 81)		p value[‡]	Age	Total (n = 153)		p value[§]
	Mean	SD	Mean	SD		rho (p value[¥])	Mean	SD	
Age (yr)	15.24	1.56	15.20	1.49	0.876		15.22	1.52	<0.001*
ANB angle	2.43	3.91	3.02	3.89	0.345	−0.126 (0.121)	2.74	3.90	0.001*
Sagittal skeletal relationship[†]									
Class III	27	37.5%	24	29.6%			51	33.3%	
Class I	20	27.8%	31	38.3%	0.359		51	33.3%	0.999
Class II	25	34.7%	26	32.1%			51	33.3%	
NSL-OP' angle	15.16	5.40	14.86	6.15	0.755	−0.155 (0.056)	15.00	5.79	<0.001*
Vertical skeletal relationship[†]									
Hypodivergent	20	27.8%	31	38.3%			51	33.3%	
Normodivergent	26	36.1%	25	30.9%	0.389		51	33.3%	0.999
Hyperdivergent	26	36.1%	25	30.9%			51	33.3%	
MGP-OP (°)	103.82	7.90	102.28	9.06	0.269	0.091 (0.261)	103.00	8.54	0.001*
Skull rotation[†]									
Posterior (<96°)	10	13.9%	21	25.9%			31	20.3%	
Average (96°–106°)	32	44.4%	37	45.7%	0.096		69	45.1%	0.001*
Previous (>106°)	30	41.7%	23	28.4%			53	34.6%	
C0–C1 (mm)	11.92	2.88	10.51	3.57	0.011*	−0.065 (0.427)	11.17	3.33	0.200
Distance C0–C1[†]									
Decreased (<4 mm)	0	0.0%	5	6.2%			5	3.3%	
Average (4–9 mm)	9	12.5%	15	18.5%	0.049*		24	15.7%	<0.001*
Increased (>9 mm)	63	87.5%	61	75.3%			124	81.0%	
H (mm)	16.77	8.97	8.52	9.07	<0.001*	0.220 (0.006*)	12.40	9.89	0.200
Position of the hyoid bone[†]									
Higher (<3 mm)	2	2.8%	26	32.1%			28	18.3%	
Average (3–7 mm)	10	13.9%	8	9.9%	<0.001*		18	11.8%	<0.001*
Lower (>7 mm)	60	83.3%	47	58.0%			107	69.9%	
NSL-OPT (°)	100.15	8.62	101.09	7.68	0.480	0.004 (0.960)	100.65	8.13	0.200
FH-OPT (°)	91.85	7.91	92.00	7.26	0.866	−0.023 (0.775)	91.93	7.55	0.200
NL-OPT (°)	92.43	8.83	92.67	7.21	0.856	−0.72 (0.378)	92.56	7.99	0.200
ML-OPT (°)	65.86	9.02	67.35	7.41	0.266	0.045 (0.584)	66.65	8.22	0.200
NSL-CVT (°)	107.63	8.99	110.53	12.06	0.236	−0.028 (0.732)	109.16	10.79	0.200
FH-CVT (°)	99.24	8.93	100.51	7.74	0.348	−0.115 (0.158)	99.91	8.32	0.200
NL-CVT (°)	99.89	9.34	101.14	8.30	0.383	−0.153 (0.058)	100.55	8.79	0.200
ML-CVT (°)	72.19	12.80	75.07	10.45	0.111	−0.123 (0.130)	73.72	11.67	0.200
NSL-RL (°)	91.50	7.60	92.05	6.11	0.207	0.029 (0.914)	91.79	6.83	0.200
FH-RL (°)	83.17	7.11	82.36	10.25	0.618	−0.043 (0.601)	82.74	8.89	0.200
NL-RL (°)	83.79	7.33	84.42	5.81	0.197	−0.076 (0.350)	84.12	6.55	0.200

[†]*Variables measured in frequency and percentage.*

[‡]*Student's t-test of independent samples with homogeneity of variances, Mann-Whitney U or Pearson's chi-square.*

[¥]*Pearson or Spearman correlation test.*

[§]*Chi square test of a sample or Kolmogorov-Smirnov.*

*p < 0.05.

SD: standard deviation; ANB: point A–nasion line to point B–nasion line; NSL-OP': nasion–sella line to occlusal plane; MGP-OP: McGregor plane to odontoid plane; H: point "h" to C3-RGn line; C0–C1: distance from C0 to C1; NSL-OPT: nasion–sella line to odontoid process tangent; FH-OPT: Frankfurt horizontal to odontoid process tangent; NL-OPT: nasal line to odontoid process tangent; ML-OPT: mandibular line to odontoid process tangent; NSL-CVT: nasion–sella line to cervical vertebral tangent; FH-CVT: Frankfurt horizontal to cervical vertebral tangent; NL-CVT: nasal line to cervical vertebral tangent; ML-CVT: mandibular line to cervical vertebral tangent; NSL-RL: nasion–sella line to ramus line; FH-RL: Frankfurt horizontal to ramus line; NL-RL: nasal line to ramus line.

T A B L E 3. Craniocervical posture parameters according to the sagittal skeletal relationship in the study sample.

Variables	ANB angle (n = 153)		Class I (n = 51)		Class II (n = 51)		Class III (n = 51)		p value‡
	r/rho	p value†	Mean	SD	Mean	SD	Mean	SD	
MGP-OP (°)	−0.222	0.006*	102.05^a	7.88	101.31^b	7.98	105.66^a	9.22	0.022*
C0–C1 (mm)	−0.100	0.217	10.75	3.49	11.09	2.67	11.69	3.73	0.509
H (mm)	0.087	0.287	12.14	9.22	13.74	10.33	11.33	10.14	0.526
NSL-OPT (°)	0.148	0.069	101.24	6.83	101.78	8.91	98.92	8.36	0.169
FH-OPT (°)	0.111	0.170	92.76	6.49	92.35	8.05	90.67	7.99	0.333
NL-OPT (°)	0.108	0.184	93.67	6.81	92.84	8.51	91.16	8.47	0.272
ML-OPT (°)	−0.075	0.356	68.47	6.94	65.18	8.98	66.29	8.41	0.120
NSL-CVT (°)	0.245	0.002*	110.90^a	7.60	110.27^a	6.82	106.31^b	15.39	0.004*
FH-CVT (°)	0.229	0.004*	102.39^a	7.41	101.00^a	6.51	96.33^b	9.62	0.002*
NL-CVT (°)	0.217	0.007*	103.47^a	8.37	101.35^a	6.88	96.82^b	9.71	0.001*
ML-CVT (°)	0.177	0.029*	78.49^a	7.56	73.80^b	8.23	68.86^b	15.54	0.001*
NSL-RL (°)	0.384	<0.001*	90.51^b	5.14	94.35^a	5.27	90.51^b	8.81	<0.001*
FH-RL (°)	0.356	<0.001*	81.98^b	5.04	85.45^a	5.43	80.78^b	13.17	<0.001*
NL-RL (°)	0.325	<0.001*	83.47^b	5.10	85.84^a	5.26	83.06^b	8.51	0.001*

†*Pearson or Spearman correlation test.*
‡*ANOVA test with Tukey's post-hoc or Kruskal-Wallis test with post-hoc pairs.*
Different letters in superscript indicate significant differences by row between the groups.
*p < 0.05.
SD: standard deviation; ANB: point A–nasion line to point B–nasion line; MGP-OP: McGregor plane to odontoid plane; H: point "h" to C3-RGn line; C0–C1: distance from C0 to C1; NSL-OPT: nasion–sella line to odontoid process tangent; FH-OPT: Frankfurt horizontal to odontoid process tangent; NL-OPT: nasal line to odontoid process tangent; ML-OPT: mandibular line to odontoid process tangent; NSL-CVT: nasion–sella line to cervical vertebral tangent; FH-CVT: Frankfurt horizontal to cervical vertebral tangent; NL-CVT: nasal line to cervical vertebral tangent; ML-CVT: mandibular line to cervical vertebral tangent; NSL-RL: nasion–sella line to ramus line; FH-RL: Frankfurt horizontal to ramus line; NL-RL: nasal line to ramus line.

T A B L E 4. Craniocervical posture parameters according to vertical skeletal relationship in the study sample.

Variables	NSL-OP' angle (n = 153)		Normodivergent (n = 51)		Hypodivergent (n = 51)		Hyperdivergent (n = 51)		p value‡
	r/rho	p value†	Mean	SD	Mean	SD	Mean	SD	
MGP-OP (°)	−0.137	0.091	104.03	7.74	104.24	9.87	100.74	7.54	0.067
C0–C1 (mm)	0.047	0.567	11.93a	3.00	10.42^b	3.22	11.18^{a,b}	3.62	0.049*
H (mm)	−0.133	0.999	12.55	9.00	13.34	10.94	11.31	9.73	0.584
NSL-OPT (°)	0.238	0.003*	100.06^{a,b}	8.07	98.82^b	8.38	103.06^a	7.46	0.012*
FH-OPT (°)	0.114	0.162	91.39	7.48	91.06	8.31	93.33	6.71	0.189
NL-OPT (°)	0.036	0.661	92.43	8.07	91.94	8.80	93.29	7.11	0.690
ML-OPT (°)	−0.369	<0.001*	66.59^{a,b}	8.63	69.61^a	8.57	63.75^b	6.31	0.001*
NSL-CVT (°)	0.134	0.098	109.06	6.89	109.22	15.34	109.22	8.42	0.251
FH-CVT (°)	−0.043	0.597	100.84	6.70	99.47	9.53	99.41	8.55	0.620
NL-CVT (°)	−0.006	0.940	101.84	7.13	100.33	10.06	99.47	8.95	0.443
ML-CVT (°)	−0.338	<0.001*	76.02^a	7.95	75.88^a	14.01	69.25^b	11.13	0.001*
NSL-RL (°)	0.216	0.007*	90.49	5.39	91.14	6.22	93.75	8.25	0.098
FH-RL (°)	0.060	0.461	80.51	11.69	83.61	6.48	84.10	7.34	0.297
NL-RL (°)	−0.017	0.834	83.39	5.53	84.61	6.82	84.37	7.26	0.900

†*Pearson or Spearman correlation test.*
‡*ANOVA test with Tukey's post-hoc or Kruskal-Wallis test with post-hoc pairs.*
Different letters in superscript indicate significant differences by row between the groups.
*p < 0.05.
SD: standard deviation; NSL-OP': nasion–sella line to occlusal plane; MGP-OP: McGregor plane to odontoid plane; H: point "h" to C3-RGn line; C0–C1: distance from C0 to C1; NSL-OPT: nasion–sella line to odontoid process tangent; FH-OPT: Frankfurt horizontal to odontoid process tangent; NL-OPT: nasal line to odontoid process tangent; ML-OPT: mandibular line to odontoid process tangent; NSL-CVT: nasion–sella line to cervical vertebral tangent; FH-CVT: Frankfurt horizontal to cervical vertebral tangent; NL-CVT: nasal line to cervical vertebral tangent; ML-CVT: mandibular line to cervical vertebral tangent; NSL-RL: nasion–sella line to ramus line; FH-RL: Frankfurt horizontal to ramus line; NL-RL: nasal line to ramus line.

between males and females [3].

The relationship of CP and sagittal SR in this study showed significance in eight of the 14 parameters evaluated, with a higher ANB angle being negatively correlated with MGP-OP and positively correlated with NSL-CVT, FH-CVT, NL-CVT, ML-CVT, NSL-RL, FH-RL, and NL-RL. Class II SRs were associated with a more extended CP versus class III and I (↑ NSL-CVT, FH-CVT, NL-CVT, NSL-RL, FH-RL, and NL-RL and ↓ MGP-OP) similar to what was found in previous studies of minors in China (NSL-VER, FH-VER, and ML-VER) [16–18], Iran (ML-VER, OPT-CVT) [19, 20], Italy (SN-OPT, NL-CVT) [21], and Peru (MGP-OP) [22]. A Class III SR was associated with a more flexed CP versus class II (↓ NSL-CVT, FH-CVT, NL-CVT, NSL-RL, FH-RL, and NL-RL and ↑ MGP-OP) as found in previous studies in populations with similar ages from China (NL-VER, ML-VER, ML-OPT, NSL-OPT, NL-OPT, and NSL-CVT) [16–18], Italy (RL-CVT) [21], Serbia (NSL-OPT) [23] and Peru (MGP-OP) [22]. These results could be due to the mechanisms of adaptation to postural balance by bone gravity in class II and III, respiratory function to increase air flow, and retroposition disorders due to the temporomandibular joint in class II and compensation of mandibular protrusion in class III [1, 13].

The relationship of CP and a vertical SR in the present study showed significance only in four out of the 14 parameters evaluated. In four CP parameters, the NSL-OP' angle was positively correlated with NSL-OPT and NSL-RL, and negatively correlated with ML-OPT and ML-CVT. Extended CP showed two parameters associated with hypodivergent SR (↑ ML-OPT and ML-CVT) and one parameter associated with hyperdivergent SR (↑ NSL-OPT). In contrast to these results, previous studies of children and adolescents in China showed a higher number of extended CP parameters associated with hyperdivergence (↑ NSL-VER, NSL-CVT, NSL-OPT, OPT-RL, CVT-RL, and OPT-CVT) than with hypodivergence (↑ ML-VER, ML-OPT, and ML-CVT) [17, 18]. The results of this study may have been affected by a higher prevalence of flexed CP in the total adolescent sample and, additionally, the study population could have been experiencing neuromuscular and joint adaptations due to bone gravity and the direction growth of craniocervical structures [1, 18, 21].

When analyzing sagittal and vertical groupings of the SRs, we found a tendency for Class II to be associated with a more extended head posture compared with Class III, which was related to a more flexed head posture, regardless of the vertical growth pattern (NSL-OPT, ML-OPT, NSL-CVT, FH-CVT, NL-CVT, ML-CVT, NSL-RL, FH-RL, and NL-RL). In contrast, only one previous study with an objective similar to the present study found no association in Turkish minors [25]. The results of this study suggest that the opposition of maxillary and mandibular skeletal discrepancies impact the maturation of the cervical spine [18]. A well-known hypothesis states that abnormal cranial inclinations with the cervical spine induce the stretching of soft tissues, limiting maxillary growth and affecting dental occlusion [13, 14]. Despite the associations found, this interpretation should be taken with caution considering that the results were obtained in a specific geographical context.

The understanding of the association between CP and SR was analyzed using multiple linear regression. The SR prediction models were statistically significant and showed moderate associations with multiple CP parameters, corroborating the complex interrelationship of the structures that comprise the CCMU [5, 17]. The sagittal and vertical SR were mutually interrelated inversely, and were associated with four common CP parameters located at the cranial base (NSL-OPT and NSL-RL) and mandibular plane (ML-OPT and ML-CVT). Specifically, a direct association was observed between NSL-OPT, ML-CVT, and NSL-RL and both the sagittal and vertical SR. This implies that corrections to inadequate forward or posterior head positions would modify the anteroposterior growth of the maxilla. It is important to include the cervical area in cephalometric measurements to improve the diagnosis and orthodontic planning of adolescents with class II and III patterns [14, 21]. Moreover, the corrections to forward head positions due to poor posture would increase vertical growth of the maxilla. It is clinically relevant to consider multi-discipline treatment to complement orthodontic treatment in adolescents who have or project hypodivergent and hyperdivergent patterns in the short term [14, 17].

The CP measurement methods used in this study are accepted in the literature [14]. The Rocabado method allows for standardized radiographic measurements of head posture; however, its validation has not been proven. The Solow method is more frequently used, but it does not include standardized ranges and has indicators that require the presence of the sixth cervical vertebra, which is infrequently taken in DLR. In this study, a larger number of control parameters from the Solow growth model proved to be useful in explaining the variables compared to Rocabado's analysis. Due to these limitations, the literature considers the method of geometric morphometry for assessing differences in the size and shape patterns of the cervical vertebrae, although its application in clinical practice is complex to evaluate [3, 18].

Regarding the sagittal and vertical SR measurement methods used in this study, ANB is the most accepted indicator for assessing anteroposterior discrepancy, although it is important to take into account that the N point may be unstable due to the growth of the anterior cranial base, and the locations of points A and B may have positioning errors [31]. Thus, the classification of vertical SR has several indicators of the bony gnathological (NSL-GoGn: angle formed between nasion–sella line and gonion–gnation line, NSL-GoMe: angle formed between nasion–sella line and gonion–mentonian line, Frankfurt mandibular plane, Bjork sum) and muscular system (lower facial height). The dental indicator used in this study, NSL-OP', is considered similar to NSL-GoGn for evaluating vertical SR. However, the NSL reference may show less accuracy than FH in distinguishing mandibular rotation [32, 33].

The present topic addresses two related clinical areas of dentistry and medicine. From the perspective of orthodontics and maxillofacial orthopedics and differential, integral, biological (skeletal, dental, muscular, and joint), and environmental diagnosis (factors related to swallowing, breathing, lifestyle habits), it is essential to include CP for preventive correction and better treatment outcomes in growing patients [13, 14]. From the public health perspective, it is important to prevent lifestyle habits that could influence poor CP, such as frequent

use of electronic devices, sedentary behavior, excessive backpack weight for school-aged children, and inadequate postural positions while doing schoolwork [28, 29].

This study has some limitations. Group selection was standardized according to the SR in order to compare the behavior of the CP; however, other factors that could have affected this relationship, such as stages of biological growth, respiratory conditions, temporomandibular disorders, and dental issues like crowding, incisal protuberances, and open bites, could not be controlled [18]. DLR data were obtained from two radiology centers using a standardized method of head position according to the Frankfurt horizontal plane, and thus, the cephalometric measurements could have been affected by differences between operators and limited the obtaining of several parameters related to Solow's VER and HOR planes. Comparisons with previous studies may have been affected by differences in cephalometric analysis regarding the definition of skeletal classes and methods for evaluating posture. This study had a cross-sectional design and covered a specific geographic sample, leading to limitations in establishing causal relationships and generalization of the results. Longitudinal and multicenter designs and methodologies that include pubertal growth and control for confounding variables are recommended for future research.

5. Conclusions

Within the limitations of this study, the following were concluded:

1. Sagittal SR analysis using the ANB angle showed a negative correlation with MGP-OP and a positive correlation with NSL-CVT, FH-CVT, NL-CVT, ML-CVT, NSL-RL, FH-RL, and NL-RL. Sagittal skeletal classes showed a significant association of Class II SR with the most extended position of the CP and Class III SR with the most flexed position of the CP, observed in the variations of MGP-OP, NSL-CVT, FH-CVT, NL-CVT, NSL-RL, FH-RL, and NL-RL.

2. Vertical SR analysis using the NSL-OP' angle showed a negative correlation with ML-OPT and ML-CVT, and a positive correlation with NSL-OPT and NSL-RL. Vertical skeletal classes did not show any associations with most of the CP parameters.

3. The evaluation of the sagittal and vertical SR groups confirmed the associations of class II with an extended cervical posture and class III with a flexed cervical posture, regardless of the vertical skeletal class.

4. The multivariable models showed that changes in CP, with decreases in MGP-OP and ML-OPT, and increases in H, NSL-OPT, ML-CVT, and NSL-RL, were moderately associated with a higher ANB, while decreases in ML-OPT, NSL-CVT and NL-RL and increases in NSL-OPT, ML-CVT, and NSL-RL, were moderately associated with a higher NSL-OP'.

5. Cephalometric analysis is a useful tool that should include an assessment of CP to evaluate and understand maxillary and cervical abnormalities in growing patients. The Solow method was more useful than the Rocabado method for explaining the relationships between the different variables.

Therefore, we recommend assessment of the functional harmony of the CCMU in adolescents as part of an interdisciplinary approach to orthodontic diagnosis and treatment.

AVAILABILITY OF DATA AND MATERIALS

The authors declare that all data supporting the findings of this study are available within the paper and any raw data can be obtained from the corresponding author upon request.

AUTHOR CONTRIBUTIONS

KLCR—wrote the manuscript and performed the data collection in compliance with the requirements for a professional degree in Peru. JADV—contributed to the idea, study design, and drafting and editing of the manuscript. KMCS—analyzed the results and writing-review of the manuscript. All authors gave their final approval and agreed to be responsible for all aspects of the work.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The Institutional Research Ethics Committee of the Universidad Científica del Sur in Lima—Peru reviewed and approved this work (No. 264-CIEI-CIENTÍFICA-2022). Informed consent was obtained from the participating adolescents and their parents for the retrospective radiographic data obtained in this study.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jocpd.com/files/article/2028754116103028736/attachment/Supplementary%20material.docx.

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