Changes in Craniocervical Posture and Cervical Curvature Across Vertical Facial Patterns : Comparative Analyses Before and After Smartphone Commercialization

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논문에 귀한 지도를 주신 이지현 교수님, 물심양면으로 도와준 후배 레지던트 선생님들, 그리고 오랜 시간 곁에서 성장의 기회를 주신 이종석 원장님께도 감사의 뜻을 전합니다.

무엇보다 긴 시간 동안 바쁜 저를 이해하고 묵묵히 지지해준 남편에게 깊은 고마움과 사랑을 전하며, 씩씩하고 밝게 자라며 큰 기쁨을 주는 아들 김진우, 그리고 따뜻한 응원과 사랑으로 늘 힘이 되어주신 양가 부모님께도 진심으로 감사드립니다.

이 자리에 이르기까지 함께해주신 모든 분들께 마음 깊이 감사드리며, 앞으로도 겸손히 배우며 성장하겠습니다. 감사합니다.

2025년 6월

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ABSTRACT

Changes in Craniocervical Posture and Cervical Curvature Across Vertical Facial Patterns: Comparative Analyses Before and After Smartphone Commercialization

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(Directed by Prof. Kyung-Ho Kim, D.D.S., M.S., PhD)

The aim of this study was to investigate differences in craniocervical posture and cervical curvature patterns across vertical facial types, and to assess how these characteristics have changed since the widespread adoption of smartphones. A total of 212 young adult females were analyzed: 99 individuals from the pre-smartphone era and 113 current smartphone users. Subjects were classified into hypodivergent (< 29°), normovergent (31° – 39°), and hyperdivergent (> 41°) groups based on the mandibular plane angle (SN-MP). Craniocervical posture and cervical curvature were evaluated using lateral cephalograms. Cervical curvature was categorized into four types: lordotic, straight, kyphotic, and sigmoid. Group comparisons were conducted using independent two-sample t-tests, one-way ANOVA with Tukey post-hoc tests, Fisher's exact test, and Pearson correlation analysis.

1. In the pre-smartphone era, craniocervical posture and cervical curvature distribution significantly differed across vertical facial groups.

2. The hyperdivergent group exhibited the most anterior head posture and the steepest anterior cervical inclination.

3. A clear association between vertical facial type and cervical curvature was observed in the pre-smartphone group, with the hyperdivergent group showing a reduced prevalence of lordotic curves.

4. In contrast, among smartphone users, craniocervical posture and cervical curvature distributions did not significantly differ between facial types.

5. Compared to the pre-smartphone group, smartphone users showed a more forward neck posture and slightly downward head tilt.

6. The overall prevalence of non-lordotic cervical curvature increased in the smartphone group, regardless of facial type.

7. Among facial types, the hypodivergent group demonstrated the most pronounced postural and curvature changes associated with smartphone use.

Key words: Craniocervical posture, Cervical curvature, Vertical facial pattern, Smartphone use

Part I:

Craniocervical Posture and Cervical Curvature Variations by Vertical Facial Pattern : Before smartphone commercialization

1. Introduction

Cervical lordosis is the anterior convexity of the cervical spine which extends from the foramen magnum to the first thoracic vertebra. Normal cervical curvature is lordotic, and proper cervical curvature is important for good posture and function of the head and neck area.[1,2]

Loss of normal cervical curvature is relatively common. Previous studies have reported that only one-third of the adult population shows lordotic cervical curvature, while the rest show straight, kyphotic (curved in the opposite direction of lordosis), or sigmoid (which has both lordotic and kyphotic curves) cervical curvature.[3,4] Loss of the normal cervical curvature can cause neurological symptoms, neck and shoulder pain, headache, temporomandibular joint dysfunction, and other disorders, thus causing functional disability.[1,5-7] Although there are many studies on the biomechanical changes that alter cervical curvature, the exact pathophysiology has not been established. It has been reported that cervical curvature can be affected by numerous factors, such as age, sex, trauma, congenital defects, cervical muscle weakness, tumors, infection, and psychosocial factors.[4,8-11] Recently, interest has been focused on the relationship between cervical curvature and posture because forward head posture is common with the use of smartphones. Forward head posture is a habitual neck posture defined by forward translation of the cervical spine and is thought to be related to cervical curvature malalignment. As the head tilt is more forward in relation to the cervical spine, the axial load moves anteriorly. Consequently, increased compressive force can trigger a progressive degenerative process and potentially result in poor alignment of the cervical curvature.[12]

Few studies have investigated the relationship between craniofacial characteristics and cervical posture.[13,14] Hellsing et al.[13] reported that subjects between the age of 8 and 15 years with dolichocephalic faces had a forwardly inclined cervical column. Similarly, Solow and Tallgren[14] investigated adult males between the ages of 22 and 30 years and reported that forward head posture was frequently associated with a large anterior facial height, maxillary and mandibular retrognathism, and large mandibular plane inclination. However, the relationship between vertical facial patterns and craniocervical posture in adult females is not assessed.

Cervical curvature can be associated with craniocervical posture and vertical facial patterns. A few studies investigated cervical curvature variations according to vertical facial patterns, but the results were controversial.[7,13-15] No studies have compared the distribution of cervical curvature type according to different vertical facial patterns. Our study is the first to establish a relationship between cervical curvature and vertical facial patterns. The purposes of this study were to (1) compare the craniocervical posture of adult females with different vertical facial patterns, (2) compare the distribution of cervical curvature variations with different vertical facial patterns, and (3) determine any correlation between the vertical facial pattern, craniocervical posture, and cervical curvature measurements.

2. Materials and Methods

This study was approved by the Institutional Review Board of the Gangnam Severance Dental Hospital (No. 3-2023-0088).

2.1 Subjects

We retrospectively analyzed the cephalometric radiographs of 1032 patients examined at the Department of Orthodontics, Gangnam Severance Dental Hospital, Yonsei University, between 2006 and 2010. Assuming that excessive smartphone use can affect the natural head posture, the period was limited to before 2010, when smartphones were not widely used.[16,17] Cephalometric radiographs were taken in the natural head position (self-balanced position) by a single technician using PMPROMAX (Planmeca, Helsinki, Finland).[18] Previous studies reported significant gender differences in the intrinsic shape of the cervical curvature,[8,9] therefore, male subjects were excluded to prevent skewing the measurements with sex-related differences, and only female subjects were included in this study. To exclude the influence of growth on cervical curvature, we selected adult subjects aged 18–35. According to previous studies,[8,19,20] only small changes in the size and curvature of the cervical spine are expected after 15 years of age, and the cervical spines of adults over the age of 50 are known to be more lordotic than those of adults under the age of 35. The inclusion criteria were (1) females aged 18–35 with a skeletal Class I relationship (0° < ANB angle < 4°), and (2) availability of a cephalometric radiograph showing at least the upper five cervical vertebral bodies and the middle aspect of the sixth cervical vertebral body (C6). The exclusion criteria were (1) history of congenital defects, (2) history of orthodontic/orthopedic treatment or surgery in the head and neck, and (3) presence of craniofacial pathologies. In the entire cohort, 101 lateral cephalometric radiographs were obtained from subjects who met the inclusion criteria. The subjects were divided into three groups according to the mandibular plane angle (the angle between the Nasion-Sella line and mandibular plane, NSL/MP): hypodivergent group (Hypo; NSL/MP < 29°), normovergent group (Norm; NSL/MP 31–39°), and hyperdivergent group (Hyper; NSL/MP > 41°).[21] The sample between the reference values of each vertical facial group was excluded, and 92 radiographs were selected as the final sample. The demographic data of the three study groups is presented in Table I-1.

Table I-1. Demographic data of the subjects

Variables	Hypodivergent (n=29)	Normovergent (n=34)	Hyperdivergent (n=29)	Total (n=92)
Age (y)	24.6 ± 5.0	24.0 ± 6.2	22.1 ± 3.7	23.6 ± 5.2
ANB (°)	2.1 ± 1.2	2.4 ± 1.0	2.8 ± 1.0	2.5 ± 1.1
NSL/ML (°)	26.4 ± 2.8	35.2 ±2.1	43.9 ± 3.3	35.2 ± 7.5

Values are presented as mean ± standard deviation
ANB, Angle between A point-Nasion-B point
NSL/ML, Angle between Nasion-Sella line and mandibular plane

2.2 Radiographic Analysis

All cephalometric radiographs were traced by one investigator who was blinded to the clinical information using V-ceph 7.0 (Cybermed, Seoul, Korea). Craniocervical posture and cervical curvature were analyzed. The lower aspects of the sixth and seventh cervical vertebral bodies (C6 and C7) were not included in the analysis because these parts were not visible on most routine orthodontic lateral cephalometric radiographs.[22]

2.2.1 Craniocervical posture

The craniocervical posture in the sagittal plane can be evaluated using two different configurations[23]: (1) the position of the head in relation to the cervical spine and (2) the inclination of the cervical spine.

(1) The Sagittal Vertical Axis (SVA)[24] : SVA is the most commonly used measure of cervical sagittal balance. SVA was defined as the horizontal distance between a plumb line dropped from the anterior margin of the external auditory meatus and the posterior superior corner of C6 (Fig. I-1). The increased distance represents a more forward shift of the head position.

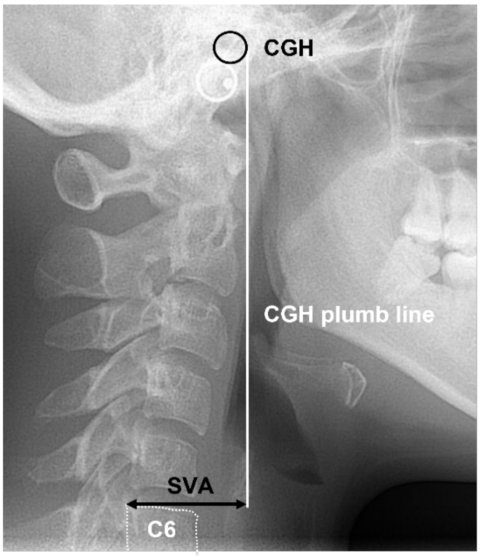


Figure I-1. Sagittal vertical axis

SVA, Sagittal Vertical Axis; CGH, center of gravity of the head; C6, sixth cervical vertebra

(2) The Cervical Inclination Angle (CIA)[25] : CIA was defined as the angle formed by the line connecting the posterior-superior corner of C6 with the centroid of the second cervical vertebra (C2) and the horizontal line. The centroid of C2 is the point at which the lines drawn between the opposing corners within C2 intersect (Fig. I-2). A more acute angle indicates a more forward inclination of the cervical spine.

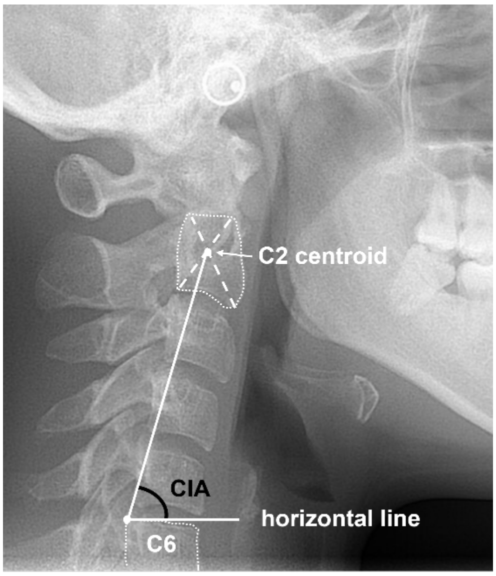


Figure I-2. Cervical inclination angle

CIA, Cervical inclination angle; C2 centroid, point where the lines drawn between the opposing corners within the second vertebra intersect; Horizontal line, true horizontal (parallel to the floor) when the subject was in natural head position

2.2.2 Cervical curvature

a. Classification

The cervical curvature was classified into 4 categories (lordotic, straight, kyphotic or sigmoid) as suggested by Beltsios et al.[4] One distance method (the Ohara method) and two angular methods (the Cobb method and the Harrison posterior tangent method) were used to evaluate cervical curvature.

(1) C2-C6 Ohara method (Figure I-3)[26]: A line was constructed to connect the midpoint of the C2 inferior end plate and C6 superior end plate. The centroids of the C3-C5 were defined as the points of intersection of lines that were drawn from opposite corners within the vertebral body. The four types of the cervical curvature were defined based on the relative positions of the C3-C5 centroids to line AB; If all centroids were anterior to line AB and maximum distance was greater than 1mm but less than 2mm, it was classified as 'lordotic'. If the distance between line AB and each centroid was less than 1mm, it was classified as 'straight'. If all centroids were posterior to line AB and the maximum distance was greater than 1mm, it was classified as 'kyphotic'. If some centroids were anterior to and some posterior to line AB, but the maximum distance was greater than 1mm, it was classified as 'sigmoid'.

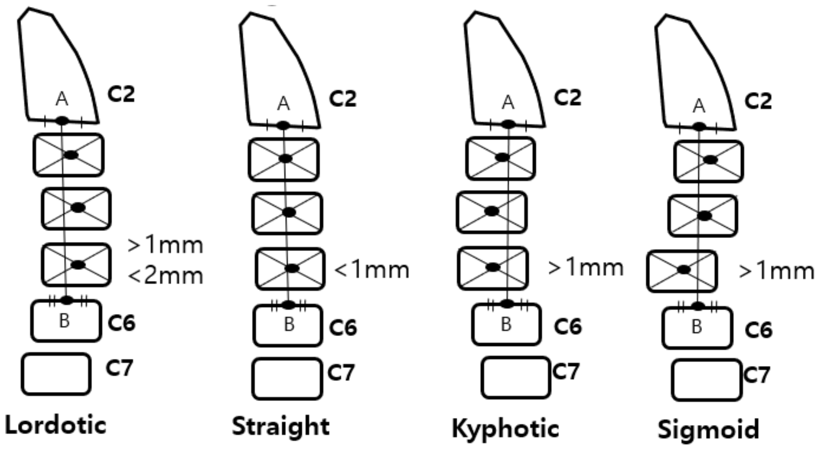


Figure I-3. Ohara method

The four types of cervical curvature are defined based on the relative positions of the C3-C5 centroids to line AB. Lordotic, all centroids are anterior to line AB and maximum distance is > 1 mm but < 2mm; Straight, the distance between line AB and each centroid is > 1 mm; Kyphotic, all centroids are posterior to line AB and the maximum distance is > 1 mm; Sigmoid, some centroids are anterior to and some posterior to line AB, but the maximum distance is < 1 mm. C7, seventh cervical vertebra

(2) **C2-C6 Cobb method** (Figure I-4)[27]: The Cobb angle is the angle between the two perpendicular lines made from the inferior margin of C2 and the superior margin of C6. When the superior margin of C6 is more clockwise than the inferior margin of C2, the angle was considered positive. Cervical spine types were classified according to the following criteria. If it is more than 7 degrees but less than 20 degrees, it is 'lordotic' curvature type, if it is -7 degrees but less than 7 degrees, it is 'straight' curvature type, and if it is -7 degrees or less, it is 'kyphotic' curvature type.

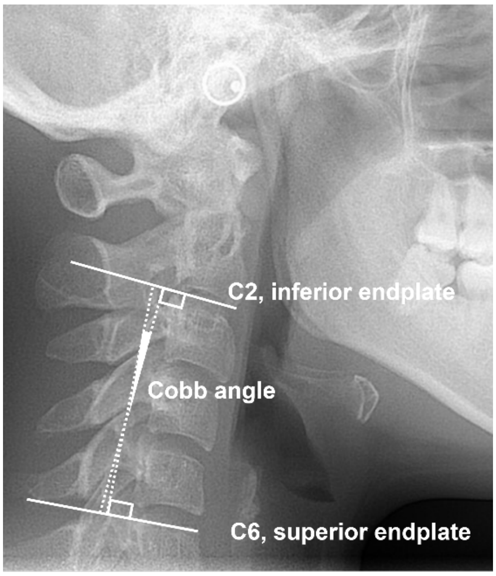


Figure I-4. Cobb angle

Angle between the two perpendicular lines made from the inferior margin of C2 and the superior margin of C6

(3) C2-C5 Harrison posterior tangent method (Figure I-5)[27]: The lines were drawn parallel to the posterior surface of each cervical vertebral body from C2 to C5 and each angle from C2 to C3, C3 to 4th cervical vertebra (C4), and C4 to C5 was added up. When the posterior surface line of lower vertebral body opened more clockwise than that of the upper vertebral body, the angle was considered positive. If the summed angle was larger than 10°, but smaller than 30°, it was classified as 'lordotic'. If the summed angle was smaller than 10°, but larger than -5°, it was classified as 'straight'. If the summed angle was smaller than -5°, it was classified as 'kyphotic'. Since this study analyzed from the middle of C6 to the upper part of cervical vertebral bodies, measurements extended only up to C5 in this method.

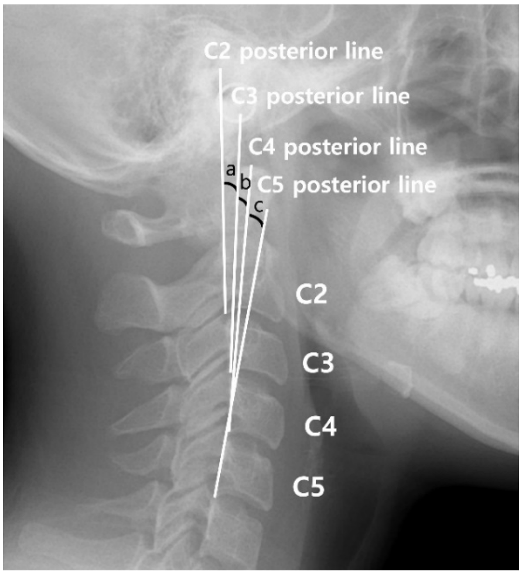


Figure I-5. Harrison posterior tangent method

The lines are drawn parallel to the posterior surface of each cervical vertebral body from C2 to C5 and each angle from C2 to C3, C3 to C4, and C4 to C5 is added. a, angle between C2 and C3; b, angle between C3 and C4; c, angle between C4 and C5

Two or more matching types in the Ohara method, Cobb method, and Harrison posterior tangent method were determined as the final cervical spine type of each sample. If the results of all three methods were inconsistent, the sample was ruled out. The sigmoid group was classified by only Ohara method because it could not be identified by Cobb method and Harrison posterior tangent method. Therefore, the sample classified as 'sigmoid' curvature type in Ohara method was determined as sigmoid regardless of the results from other angular methods.

b. Distribution

The distribution of the cervical curvature type in different vertical facial groups was examined. We compared the differences in overall cervical curvature distribution among three vertical facial groups.

2.3 Statistical Analysis

To determine the magnitude of measurement errors, we used Dahlberg's formula.[28] Twenty lateral cephalometric radiographs were randomly selected, and same examiner traced and measured at 2-week intervals. The intraclass correlation coefficients (ICC) for the reliability of the variables were all greater than 0.97.

All analyses were performed using SPSS software (version 23, IBM Corp., Armonk, NY, USA). Statistical significance was set at $p < 0.05$. Descriptive statistics, including the mean, standard deviation for all variables, were calculated. The normality of continuous variables was assessed using the Shapiro-Wilk test.

The differences in the lateral cephalometric variables for craniocervical posture and cervical curvature among the three groups were tested using one-way analysis of variance (ANOVA) with Bonferroni post-hoc test. The difference in overall distribution among three vertical facial groups and the difference in the proportion of each cervical curvature type were assessed by the Fisher's exact test with Bonferroni post-hoc test. First, an overall comparison was conducted. Secondly, the cervical curvature was categorized in two groups, lordotic curve and non-lordotic group.

To investigate the correlations between measured values, Pearson's correlation coefficients were calculated. Despite the more severe condition of the sigmoid curvature samples, it was excluded from correlation analysis because the measured values did not differentiate it from the lordotic group and straight groups.[29] Since the variable in Ohara method is a nominal variables, it was excluded from descriptive statistics and correlation analysis

3. Results

3.1 Craniocervical posture and cervical curvature (Table I-2)

The Hyper group showed a larger SVA than the Hypo group. Clinically, this indicates that the subjects in the Hyper group had a more forward head posture. Likewise, the Hyper group showed smaller CIA than the Norm and Hypo groups, suggesting a more forwardly inclined cervical column in the Hyper group. In contrast, the cervical curvature measurements did not show any statistical differences.

Table I-2. Comparisons of craniocervical posture and cervical curvature measurements according to vertical facial patterns

	Hypodivergent (n=29)	**Normovergent (n=34)**	**Hyperdivergent (n=29)**	***p*-value**
Craniocervical posture				
Sagittal vertical axis (mm)	14.4 ± 4.5[a]	17.3 ± 4.8[a,b]	20.0 ± 5.5[b]	0.000***
Cervical inclination angle (°)	85.3 ± 4.2[a]	84.5 ± 2.9[a]	79.7 ± 3.9[b]	0.000***
Cervical curvature				
Cobb angle (°)	-0.8 ± 9.8	-3.9 ± 12.0	-6.4 ± 8.0	0.123
Harrison posterior tangent angle (°)	2.1 ± 8.8	1.7 ± 11.6	-2.7 ± 9.1	0.134

Values are presented as mean ± standard deviation
Analysis of variance was performed to compare the variables among three facial patterns
Post-hoc test was done with the Bonferroni method.
a, b: Different superscript letters indicate statistical difference among three groups. Same letter means there is no difference between groups (****p*< 0.001).

3.2 Cervical curvature classification (Table I-3)

As a result of observing the final determined cervical curvature in the total sample, the straight cervical type was the most common (48.9%), followed by kyphotic (25.0%), lordotic (19.6%), and sigmoid (6.5%) types.

Table I-3. Classification of cervical curvature

Curvature Measurement Method	Cervical Curvature Classification			
	Lordotic	Straight	Kyphotic	Sigmoid
Ohara method	17 (18.5%)	47 (51.1%)	22 (23.9%)	6 (6.5%)
Cobb method	15 (16.3%)	44 (47.8%)	27 (29.3%)	6 (6.5%)
Harrison posterior tangent method	16 (17.4%)	47 (51.1%)	23 (25.0%)	6 (6.5%)
Final curvature	18 (19.6%)	45 (48.9%)	23 (25.0%)	6 (6.5%)

3.3 Distribution of cervical curvature by each vertical facial pattern

The distribution of cervical curvature types by each vertical facial pattern was compared (Figure I-6). In the Hypo group, the ratio of straight curvature was the highest (65.5%), followed by lordotic (17.2%), kyphotic (13.8%), and sigmoid curvature (3.4%). In the Norm group, lordotic curvature showed the highest ratio (32.4%), straight and kyphotic curvature showed the same ratio (29.4%), and sigmoid curvature showed the least (8.8%). In Hyper group, the ratio of straight curvature was the highest (55.2%), followed by kyphotic curvature (31.0%). The ratio of lordotic curvature and sigmoid curvature was the same (6.9%).

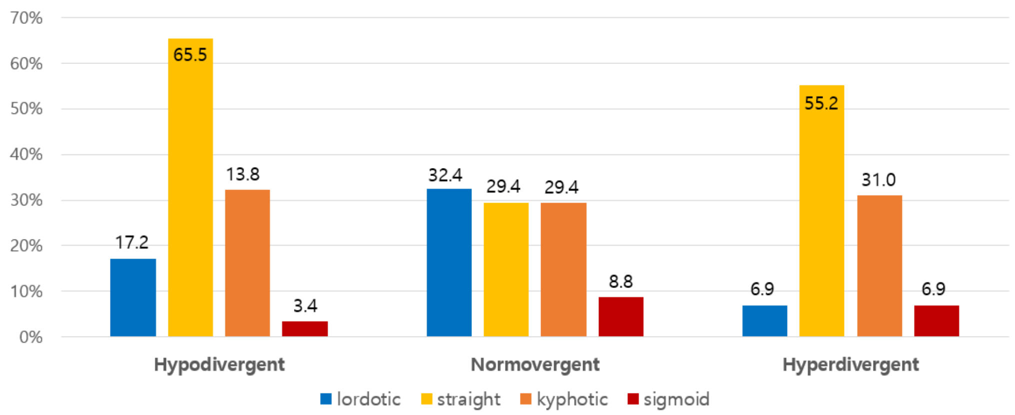


Figure I-6. Distribution of cervical curvature types by vertical facial pattern

Fisher's exact test was conducted to examine the association between the three vertical facial patterns and four cervical curvature types (Table I-4). Significant differences were found in the distribution of cervical curvature types among the groups (p = 0.035). Even though the post-hoc test did not reveal any significant pairwise difference ($p > 0.05$), based on the difference between the expected and observed frequencies, it can be inferred that there was a higher incidence of lordotic curves and a lower incidence of straight curves in the Norm group. In contrast, the Hypo group showed a higher incidence of straight curves.

Table I-4. The distribution of cervical curvature by the vertical facial type in the sample

Variables	Lordotic	Straight	Kyphotic	Sigmoid	*p*-value†
Hypodivergent (n=29)	5	19	4	1	0.035*
Normovergent (n=34)	11	10	10	3	
Hyperdivergent (n=29)	2	16	9	2	
Post-hoc *p*-value‡	Hypodivergent vs Normovergent				0.119
	Hypodivergent vs Hyperdivergent				0.884
	Normovergent vs Hyperdivergent				0.146

† Fisher's exact test was performed to compare among 4 types of cervical curvature in each facial types

‡ Bonferroni post-hoc test was done. Bonferroni p values are shown in the table

*$p < 0.05$

After categorizing the cervical curvatures into normal (lordotic) and abnormal (straight, kyphotic, and sigmoid) curves, the Norm group showed the highest percentage of lordotic curvature (32.4), followed by the Hypo (17.2) and Hyper (6.9) groups (Figure I-7).

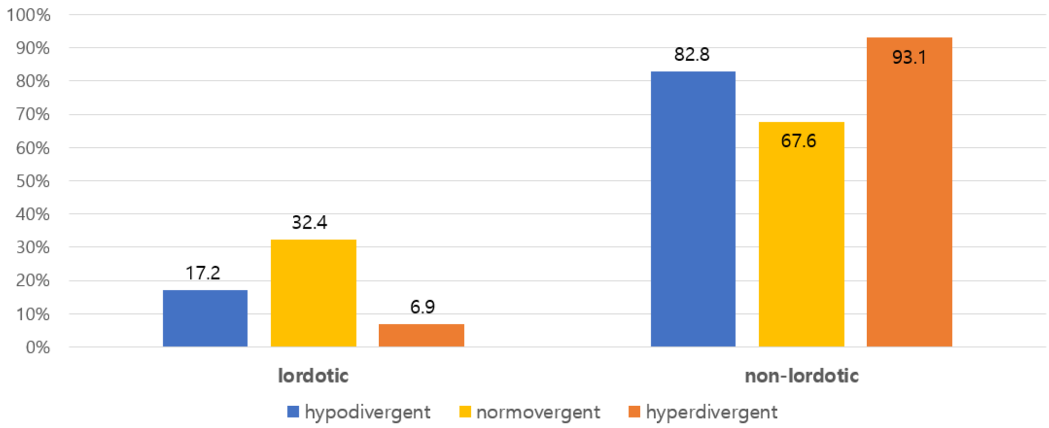


Figure I-7. Distribution of cervical curvature types by lordotic and non-lordotic curve

Fisher's exact test indicated an association between the vertical facial pattern and cervical curvature (Table I-5). According to post-hoc testing, there was a difference in distribution between the Norm and Hyper groups. A higher incidence of lordotic curvature and lower incidence of non-lordotic curvature were observed in the Norm group.

Table I-5. Comparison of the distribution of lordotic versus non-lordotic[a] cervical curvature types by each vertical facial pattern

Variables	Lordotic	Non-lordotic	*p*-value[†]
Hypodivergent (n=29)	5	24	0.037*
Normovergent (n=34)	11	23	
Hyperdivergent (n=29)	2	27	
Post-hoc *p*-value[‡]	Hypodivergent vs Normovergent		0.741
	Hypodivergent vs Hyperdivergent		1.000
	Normovergent vs Hyperdivergent		0.039*

[a]non-lordotic cervical curvature included straight, kyphotic and sigmoid curve

[†] Fisher's exact test was performed to compare among 2 types of cervical curvature in each facial types

[‡] Bonferroni post-hoc test was done. Bonferroni *p* values are shown in the table

$*p < 0.05$

3.4 Correlation among vertical facial patterns, craniocervical posture, and cervical curvature (Table I-6)

A correlation analysis was conducted to investigate the linear relationship between the vertical facial pattern (NSL/ML), craniocervical posture, and cervical curvature. There was a moderate correlation between the craniocervical postures (SVA and CIA) and vertical facial patterns (NSL/ML) ($p > 0.05$). SVA was positively related to NSL/ML (r = 0.391), and negatively related to CIA (r = -0.468). This indicates that the more vertical the facial type, the greater the increase in the forward position of the head and forward inclination of the cervical column. However, a weak correlation was found between NSL/ML and cervical curvature measurements (Cobb method: r = -0.238; Harrison method: r = -0.192). The craniocervical posture and cervical curvature measurements also showed a weak correlation. The Cobb angle showed weak correlations with SVA (r = -0.299) and CIA (r= 0.250). In contrast, the Harrison posterior tangent angle did not show any significant correlation with SVA or CIA ($p > 0.05$). The SVA and CIA were strongly correlated (r = -0.845), and the Cobb angle and Harrison angle were also highly correlated (r = 0.901).

Table I-6. Pearson's correlation coefficient between the measurements

Variables	**NSL/ML**	**Sagittal vertical axis**	**Cervical inclination angle (°)**	**Cobb angle (°)**	**Harrison posterior tangent angle (°)**
NSL/ML **(*p*-value)**		0.391** (0.000)	-0.468** (0.000)	-0.238** (0.022)	-0.192 (0.066)
Sagittal vertical axis **(*p*-value)**			-0.845** (0.000)	-0.299** (0.004)	-0.184 (0.079)
Cervical inclination angle **(*p*-value)**				0.250** (0.016)	0.182 (0.082)
Cobb angle (°) **(*p*-value)**					0.901*** (0.000)

ANB, Angle between A point-Nasion-B point; NSL/ML, Angle between Nasion-Sella line and mandibular plane

Pearson correlation analysis was performed to evaluate the relationship between the variables.

$^*p< 0.05$, $^{**}p< 0.01$, $^{***}p< 0.001$

Subjects with sigmoid curvature were excluded.

4. Discussion

The relationship between the sagittal facial patterns and the type of cervical curvature remains controversial.[13,14,30] To exclude the effects of the anteroposterior skeletal discrepancy on the type of cervical curvature, we only investigated patients with a skeletal Class I relationship.

This study used two measurements of craniocervical posture (SVA and CIA) and three methods of cervical curvature (Ohara, Cobb and Harrison posterior tangent methods). Introduced in 1889, SVA is the most commonly used method to measure the anteroposterior head position. However, it has the limitation of being affected by individual size differences.[19] Therefore, the CIA method, which measures the degree of head tilt, was used. However, the CIA considers only the position of the cervical vertebrae and and does not use any reference to the head. Both methods were employed to evaluate craniocervical posture for a more accurate analysis. The Cobb method is the most widely used method for cervical curvature measurement because of its ease of use and good intra- and interrater reliability. In contrast, the Harrison posterior tangent method is the most accurate method for measuring cervical curvature.[1,27] However, these angular methods cannot discriminate between a segmental reversed curvature (sigmoid) and a lordotic or straight one; therefore, the Ohara method, which can distinguish regional kyphotic curvatures, was also utilized.[31]

In previous dental studies, cervical curvature had been analyzed by cervical lordosis angle (CLA), down-opened angle between odontoid process tangent and a line through the infero-posterior points of C2 and C4.[7,30] This method only measures up to C4 due to the limitations of the dental cephalometric radiographs, which make it difficult to observe the entire cervical spine. Consequently, no study has provided a guide for classifying the cervical curvature type using the CLA. Meanwhile, the Cobb method and the Harrison posterior tangent method, which are primarily used in spinal diagnosis and treatment-related studies, provide data on the values of each cervical spine vertebra, suggesting a criterion for classifying cervical curvature.[1,32-34] Therefore, we utilized these methods in lieu of the CLA.

4.1 Craniocervical posture

Based on SVA and CIA values, the Hyper group was distinguished from the other groups. The Hyper group showed a more anterior position of the head and increased anterior inclination of the cervical spine than the Hypo group. Our findings are similar to previous studies that reported a correlation between large vertical craniofacial dimensions and extended head posture.[14,35-37] This mechanism can be explained by 'neuromuscular feedback' and is termed the 'soft-tissue stretching hypothesis.' This hypothesis suggests that the soft tissue layer is passively stretched when the head is extended relative to the cervical vertebral column. This would increase forces on the skeletal structures and could redirect the mandibular growth more caudally.[30] Consequently, subjects with a hyperdivergent facial pattern or a retrognathic profile are likelier to exhibit a forward craniocervical posture.

4.2 Cervical curvature angle

The three groups had no significant differences in the Cobb angle and Harrison posterior tangent angle. As these angles serve as criteria for classifying cervical types, comparing these angles between the three groups when all cervical curvature types are intermixed seems to have no clinical significance. For this reason, it would be more meaningful to ascertain the distribution of cervical curvature types for each vertical facial pattern and compare the differences in these distributions.

4.3 Cervical curvature classification

Cervical curvature was classified into five categories within each group. It is well accepted that the physiological cervical curvature is lordotic in a natural head posture. However, our results showed that only 19.6% of the samples had lordotic cervical curvature. A straight cervical curvature was the most common (48.9%), followed by kyphotic (25.0%), lordotic (19.6%), and sigmoid (6.0%) curvatures. In previous studies, lordotic cervical curvature was not dominant. Beltsios et al[4] conducted a study on 100 healthy adults and reported that approximately one-third of the population had a lordotic cervical spine, one-third had a straight spine, and the remaining third had either kyphotic or sigmoid curvatures. Yu et al[3] reported that 28% of young Chinese adults have lordotic cervical spines, whereas 45% have straight spines. Nonetheless, compared to previous findings, our results indicate a lower proportion of lordotic cervical curvature.

4.4 Distribution of cervical curvature by each vertical facial pattern

This is the first study to describe the prevalence of each type of cervical curvature in different vertical facial patterns. In the Hypo and Hyper groups, the straight curve was most prominent, whereas in the Norm group, the lordotic curve was most prevalent. Fisher's exact test indicated an association between the vertical facial pattern and the type of cervical curve. The Norm group had a higher frequency of lordotic curves and fewer straight curves, the Hypo group had a predominance of straight curves, and the Hyper group had fewer lordotic curves. As expected, there was a higher ratio of non-lordotic cervical curvature in the Hyper group, which tended to show a forward head posture. However, the prevalence of a straight curvature was higher in the Hypo group. Fineman et al[38] reported that subjects who changed from a neutral position to a military posture (backward craniocervical posture) often experienced the loss of cervical lordosis, resulting in a straight posture. Variations in muscle tension around the shoulder and neck areas may play a role.[39] Additional research, such as biomechanical analysis, is needed to validate this hypothesis. Compared with previous studies,[3,4,40] the distribution of cervical curvature types in the Norm group was similar, but the Hypo and Hyper groups showed a higher proportion of non-lordotic cervical curvatures. In this study, although there were no significant differences in the mean values of cervical curvature measurements, the distribution of cervical curvature types showed a significant difference between the three groups. This may be linked to the observation that the Hypo group had the highest proportion of straight curves and the lowest proportion of kyphotic curves, whereas the Norm group had an even distribution for each curvature type.

4.5 Correlation between the vertical facial pattern, craniocervical posture, and cervical curvature

In this study, we investigated the correlations among NSL/ML, craniocervical posture, and cervical curvature. The Pearson correlation suggests that the NSL/ML showed a moderate correlation with craniocervical posture, implying that head and cervical postures may vary according to the vertical facial pattern, aligning with the aforementioned soft tissue stretching hypotheses. Thus, an increase in the mandibular plane angle was associated with a more anterior positioning of the head and neck. Our results showed a weak negative correlation between NSL/ML and cervical curvature measurements. This suggests that an increase in the mandibular plane angle corresponds to a decrease in cervical curvature; however, when examining the distribution of cervical curvature types, no difference was observed between the Hyper and Hypo groups. Tecco et al[7] found no significant differences in cervical curvature relative to vertical facial patterns. Their study was limited in not including kyphotic cervical curvature since kyphosis is not considered a physiological posture of the spine. Solow and Tallgren[14] observed a very weak negative correlation between the mandibular plane angle and cervical lordosis angle(the angle between odontoid process tangent and a line through the inferoposterior points of C2 and C4, CLA), noting reduced CLA in association with large vertical facial dimensions and increased CLA with a shorter vertical dimension. However, these studies were conducted with adult men; therefore, the results cannot be directly compared with those in our study. This indicates that the cervical curvature type cannot be explained solely by the magnitude of the mandibular plane angle. Examination of the relationship between craniocervical posture and cervical curvature measurements revealed that the Cobb angle had a weak correlation with craniocervical posture, whereas the Harrison posterior tangent angle showed no correlation. There are two possible explanations for this minimal correlation. First, a backward craniocervical posture may affect cervical curvature. Typically, a more lordotic curvature is expected with a more backward head position; however, this study found a prevalence of straight curvatures associated with such a posture. Second, cervical curvature may be affected by a multitude of factors, with craniocervical posture being one of the many potential influences.[41]

The mechanism underlying loss of cervical lordosis remains unclear. A recent hypothesis is that weakness of the neck extensor muscles is a risk factor for the development of cervical kyphosis.[42] Studies on the association between forward head posture and neck muscle imbalance have been reported.[43] Therefore, it is reasonable to assume that neck muscle imbalance according to different cervical postures may affect cervical spine curvature. Although muscular factors may influence posture, studies evaluating neck musculature by facial pattern remain limited.[44] Furthermore, functional anatomical factors such as airway dimensions or hyoid bone position may also play a role in determining cervical posture, particularly among hyperdivergent individuals.[14,45-47] Although these aspects were not measured in the present study, their reported associations with forward head posture and compensatory cervical extension warrant attention in future investigations.

These findings provide foundational insight into the relationship between vertical facial patterns and craniocervical posture and cervical curvature. The next section examines how these structural patterns respond to behavioral influences, particularly smartphone use.

Part II:

Comparisons in craniocervical posture and cervical curvature type according to different vertical facial type : Before and after smartphone commercialization

1. Introduction

The widespread adoption of smartphones has raised concerns about craniocervical health.[48,49] Habitual forward and downward head posture during smartphone use may alter craniocervical posture and cervical spine curvature.[50,51] In South Korea, smartphone use surged following the launch of the iPhone in November 2009, reaching near 100% penetration among adults aged 19–35 by 2015.[52] That year, Korean university students reported an average daily smartphone usage of 5.35 hours and an average usage duration of 4.41 years, indicating the widespread adoption of smartphones into daily life.[53] While previous studies have linked smartphone use to forward head posture and cervical alignment changes,[54,55] their interaction with skeletal morphology remains unclear.

Beyond cervical curvature, sagittal craniocervical posture is critical for head and neck alignment. The sagittal plane is evaluated via head rotation (vertical tilt: where the head is tilted upward (extension) or downward (flexion) relative to the cervical spine) and translation (anteroposterior displacement, where the head is positioned forward or backward along the horizontal axis without tilting). Several studies have reported that forward head posture correlates with cervical malalignment.[56,57] One study that evaluated both head translation and rotation found that a posteriorly translated, extended (upwardly tilted) head position maintains normal cervical lordosis, while an anteriorly translated, flexed (downwardly tilted) head posture often leads to kyphosis and cervical misalignment and biomechanical instability.[58]

In our previous study, we reported that craniocervical posture and cervical curvature vary by vertical facial pattern.[59] Specifically, individuals with a hyperdivergent facial pattern typically exhibit forward head posture and non-lordotic curvature (straight/kyphotic/sigmoid). However, these findings were based on individuals who had not yet been exposed to habitual smartphone-related postures, leaving it unclear whether skeletal tendencies persist in modern populations regularly subjected to forward head positioning. Other studies[37,60] involving individuals with a high mandibular plane angle note a forward head shift with extension, which contrasts with the forward shift and flexed posture typically observed in smartphone users. These differences influence orthodontic diagnosis (e.g., mandibular-cervical relationships),[61] facial aesthetics (e.g., head–neck harmony),[62] and musculoskeletal balance (e.g., cervical load).[18,21]

Although the effects of smartphone use on craniocervical posture and cervical curvature have been widely documented, individual variability in these responses remains poorly understood. In particular, skeletal characteristics such as vertical facial pattern may influence the degree and nature of postural adaptations. However, no study has systematically examined these differences across facial types or compared pre- and post-smartphone era cohorts within the same vertical pattern.

While this investigation builds upon our previous study, which examined craniocervical posture and cervical curvature differences across vertical facial patterns prior to widespread smartphone adoption, the current study incorporates several key methodological differences. First, the pre-smartphone cohort was expanded to 99 participants through the inclusion of additional cases from 2005, in order to enhance statistical power and group comparison stability. Second, vertical head rotation was newly assessed via the NSL/VER angle, based on the hypothesis that skeletal patterns may influence not only head translation but also rotation. Third, because our previous analysis demonstrated a high correlation between cervical inclination angle (CIA) and sagittal vertical axis (SVA), only CIA was used to evaluate anterior head inclination in this study. Finally, correlation analysis was excluded, given that prior results indicated limited clinical interpretability for such associations.

Therefore, this study aimed to: (1) evaluate craniocervical posture and cervical curvature differences among vertical facial subgroups in smartphone users; (2) compare these parameters between smartphone users and the control group; and (3) assess group differences within each vertical facial pattern subgroup to determine whether change magnitude varies by facial pattern.

2. Materials and Methods

This study was approved by the institutional review board of the Gangnam Severance Dental Hospital (No. 3-2023-0088).

2.1 Subjects

Participants were initially selected from two time-based cohorts: 1,032 patients (2005–2010, pre-smartphone era) and 1,253 patients (2015–2022, post-smartphone era). Inclusion and exclusion criteria were identical to those described in Part I. Following the application of these criteria, participants were categorized into two groups: controls (no smartphone use) and smartphone users (≥ 1 hour/day for > 1 year). The selection of the post-2015 cohort as the smartphone user group was based on national survey data showing that, since 2015, smartphone penetration among Korean adults aged ≤ 60 has reached nearly 100%.[52] All lateral cephalometric radiographs were obtained using the PMPROMAX system (Planmeca, Helsinki, Finland), in the natural head position (self-balanced posture), following the same protocol as in Part I. Subjects were further grouped into hypodivergent (< 29°), normovergent (31 – 39°), and hyperdivergent (> 41°) skeletal types. Demographic characteristics are presented in Table II-1.

Table II-1. Demographic data of the subjects

Variables	Hypodivergent (n=61)		Normovergent (n=84)		Hyperdivergent (n=67)		Total (n=212)	
	Control (n=30)	Smartphone user (n=31)	Control (n=36)	Smartphone user (n=48)	Control (n=33)	Smartphone user (n=34)	Control (n=99)	Smartphone user (n=113)
Age (year)	24.6 ± 5.0	25.2 ± 6.8	24.0 ± 6.2	24.4 ± 5.2	22.1 ± 3.7	24.9 ± 5.6	23.6 ± 5.2	24.8 ± 5.8
ANB (°)	2.1 ± 1.2	2.1 ± 1.1	2.5 ± 1.1	2.6 ± 1.0	2.8 ± 1.0	2.4 ± 1.0	2.5 ± 1.1	2.4 ± 1.1
NSL/ML (°)	26.4 ± 2.7	26.1 ± 2.6	35.3 ± 2.1	35.6 ± 2.6	43.3 ± 3.2	43.9 ± 3.3	35.2 ± 7.5	35.1 ± 6.9

Values are presented as mean ± standard deviation.

ANB, Angle between A point-Nasion-B point

NSL/ML, Angle between Nasion-Sella line and mandibular plane

2.2 Radiographic Analysis

All cephalometric radiographs were traced by a single blinded investigator using V-ceph 7.0 software (Cybermed, Seoul, Korea). The lower aspect of C6 and the seventh cervical vertebra (C7) were excluded due to frequent invisibility on routine lateral cephalometric radiographs. Modified measurement methods were applied to account for limited visibility of the lower cervical spine, which typically extended only to the mid-C6 in most radiographs.[22,59]

2.2.1 Craniocervical posture

Craniocervical posture in the sagittal plane was evaluated using the following parameters:

(1) Nasion-Sella line to VER (NSL/VER)[14]: Defined as the angle between the nasion-sella line and the true vertical line, which is perpendicular to the floor (Figure II-1). This angle was used to assess head rotation in the sagittal plane. A larger angle indicates a more extended head posture, while a smaller angle reflects head flexion.

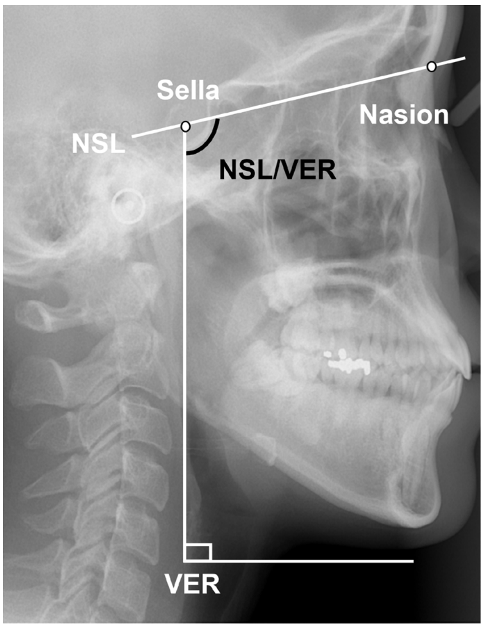


Figure II-1. Nasion-Sella line to true vertical line

NSL; Nasion-Sella line, VER; vertical to the lower border of the film and parallel to the gravity force

(2) Cervical inclination angle (CIA)[25]: The measurement method and interpretation were identical to those described in Part I (see Figure I-2).

2.2.2 Cervical curvature

a. Classification

Cervical curvature classification and measurement methods in this study were identical to those used in Part I. Curvature was evaluated using three established techniques: the Ohara method, the Cobb method, and the Harrison posterior tangent method (see Figures I-3, I-4, and I-5 in Part I). Detailed descriptions and illustrations of these methods are provided in Part I (Radiographic Analysis). The final curvature type was determined when at least two of the three methods agreed. Cases with completely discordant results were excluded. Sigmoid curvature classification was made exclusively based on the Ohara method, due to its superior ability to detect this pattern.

b. Distribution

The distribution of cervical curvature types was analyzed according to smartphone use and vertical facial pattern. First, differences among vertical pattern subgroups within the smartphone group were examined. Second, overall differences between the smartphone and control groups were compared. Finally, distribution differences between the two groups were assessed within each vertical pattern subgroup.

2.3 Statistical Analysis

Measurement error was evaluated using Dahlberg's formula.[28] Cephalometric radiographs of 20 randomly selected participants were retraced and remeasured after a 2-week interval. The intraclass correlation coefficient (ICC) for all variables exceeded 0.95.

All analyses were performed using SPSS software (version 23, IBM Corp., Armonk, NY, USA), with statistical significance set at $p < 0.05$. Descriptive statistics (mean, standard deviation, and range) were calculated for all variables. The normality of continuous variables was assessed using the Shapiro-Wilk test.

Group comparisons of craniocervical posture among vertical subgroups within the smartphone group were conducted using one-way analysis of variance (ANOVA) with Bonferroni post hoc tests. Control-smartphone group comparisons used independent t-tests. Corresponding vertical subgroup differences were also analyzed using independent t-tests.

Variation in postural change across facial types was assessed by calculating the difference in cervical inclination angle (ΔCIA) between groups, compared using one-way ANOVA with Tukey's honestly significant difference post hoc test. Cervical curvature distribution was analyzed using chi-square tests, applying Bonferroni correction when appropriate.

3. Results

3.1 Craniocervical posture

3.1.1 Craniocervical posture by vertical facial pattern within the smartphone user group (Table II-2)

The NSL/VER significantly differed among the Hypo, Norm, and Hyper subgroups within the smartphone user group ($p < 0.001$). The Hypo group exhibited the smallest NSL/VER value, suggesting a more pronounced head flexion. However, the CIA showed no significant differences among subgroups, suggesting comparable anteroposterior head translation across groups.

Table II-2. Comparisons of craniocervical posture among different vertical facial pattern

Variables	Hypodivergent (n=31)	Normovergent (n=48)	Hyperdivergent (n=34)	*p*-value
NSL/VER (°)	96.3 ± 4.3 [a]	98.9 ± 3.4 [b]	100.5 ± 2.8 [c]	***
Cervical inclination angle (°)	76.7 ± 6.5	76.6 ± 5.7	74.7 ± 5.9	*NS*

Values are presented as mean ± standard deviation
NSL/VER, Angle between Nasion-Sella line and true vertical line (vertical to the lower border of the film and parallel to the gravity force)
a, b, c: Different superscript letters indicate statistical difference among the hypodivergent, normovergent, and hyperdivergent groups
NS; Not significant., $^{**}p < 0.01$, $^{***}p < 0.001$

3.1.2 Craniocervical posture: Comparison between control and smartphone user groups (Table II-3)

The smartphone user group demonstrated significantly smaller NSL/VER values than the control group ($p < 0.05$), indicating a more flexed head posture. The CIA was also significantly reduced in the smartphone group ($p < 0.001$), demonstrating greater forward head translation.

Table II-3. Comparison of craniocervical posture between the control and the smartphone group in same vertical facial pattern subgroup

Variables	Hypodivergent (n=60)			Normovergent (n=83)			Hyperdivergent (n=61)			Total (n=204)		
	Control (n=30)	Smartphone (n=31)	*p*-value	Control (n=36)	Smartphone (n=48)	*p*-value	Control (n=33)	Smartphone (n=34)	*p*-value	Control (n=99)	Smartphone (n=113)	*p*-value
NSL/VER (°)	98.0 ± 2.8	96.3 ± 4.3	*NS*	99.7 ± 2.6	98.9 ± 3.4	*NS*	101.5 ± 2.9	100.5 ± 2.8	*NS*	99.7 ± 3.1	98.7 ± 3.8	*
Cervical inclination angle (°)	85.5 ± 4.2	76.7 ± 6.5	***	84.3 ± 3.7	76.6 ± 5.7	***	80.0 ± 4.3	74.7 ± 5.9	***	83.1 ± 4.7	76.0 ± 6.0	***

Values are presented as mean ± standard deviation

NSL/VER, Angle between Nasion-Sella line and true vertical line (vertical to the lower border of the film and parallel to the gravity force)

NS; Not significant., *$p< 0.05$, **$p< 0.01$, ***$p< 0.001$

3.1.3 Craniocervical posture: Comparison between control and smartphone user groups within each vertical facial pattern (Table II-3)

The smartphone user group exhibited significantly smaller CIA values than the control group across all vertical facial pattern subgroups ($p < 0.001$), indicating greater forward head translation in each subgroup (Hypo, Norm, and Hyper). NSL/VER showed no significant differences between groups within any facial pattern subgroup.

3.1.4 Comparison of postural change (ΔCIA) among vertical facial pattern subgroups (Table II-4)

The postural change of cervical inclination angle (ΔCIA) was significantly greater in the Hypo group than in the Norm and Hyper groups ($p < 0.05$), indicating that the Hypo group experienced the most pronounced forward cervical inclination associated with smartphone use. Post hoc analysis revealed this difference was statistically significant only between Hypo and Hyper subgroups ($p < 0.05$), while Hypo-Norm and Norm-Hyper comparisons did not reach statistical significance.

Table II-4. Comparison of ΔCIA among vertical facial pattern subgroups

Variables	Hypodivergent	Normovergent	Hyperdivergent	*p*-value
ΔCervical inclination angle (°)	5.9 ± 4.4[a]	2.1 ± 3.8[b]	2.1 ± 4.7[b]	*

Values are presented as mean ± standard deviation
NSL/VER, Angle between Nasion-Sella line and true vertical line (vertical to the lower border of the film and parallel to the gravity force)
⊿CIA, change in cervical inclination angle
* $p < 0.05$

3.2 Cervical curvature

3.2.1 Cervical curvature by vertical facial pattern within the smartphone user group (Table II-5 and Figure II-2)

In the Hypo subgroup, straight curvature was the most prevalent (41.9), followed by kyphotic (32.3%), sigmoid (22.6%), and lordotic (3.2%) curvatures. The Norm subgroup showed a similar prevalence: straight (41.7%), kyphotic (31.3%), sigmoid (16.7%), and lordotic (10.4%). The Hyper subgroup demonstrated a distinct pattern, with kyphotic curvature being the most prevalent (38.2%), followed by straight (26.5%), sigmoid (23.5%), and lordotic (11.8%) curvatures. However, no significant differences in distribution emerged among the three subgroups ($p > 0.05$).

Table II-5. Comparison of cervical curvature type distribution among different vertical facial pattern subgroups

	Lordotic	Straight	Kyphotic	Sigmoid	*P*-value
Hypodivergent	1 (3.2)	13 (41.9)	10 (32.3)	7 (22.6)	
Normovergent	5 (10.4)	20 (41.7)	15 (31.3)	8 (16.7)	*NS*
Hyperdivergent	4 (11.8)	9 (26.5)	13 (38.2)	8 (23.5)	

Data are presented as n (percentage); % symbol omitted.

NS; Not significant

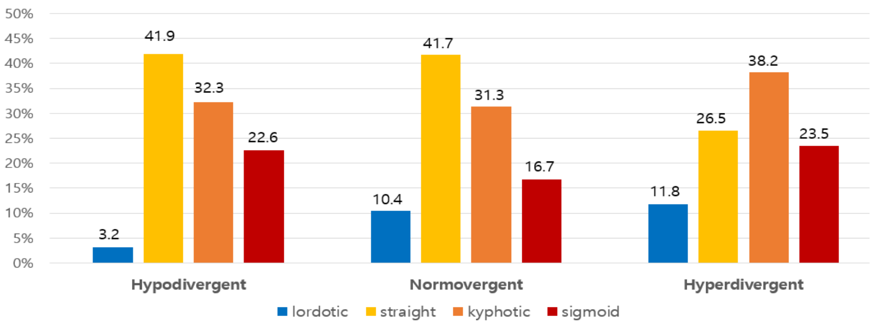


Figure II-2. The distribution of cervical curvature types by vertical facial pattern in the smartphone group

3.2.2 Distribution of cervical curvature: Comparison between control and smartphone user groups (Table II-6 and Figure II-3)

The control group showed: lordotic (20.2%), straight (47.5%), kyphotic (25.3%), and sigmoid (7.1%) curvatures. The smartphone group demonstrated: lordotic (9.7%), straight (38.1%), kyphotic (31.9%), and sigmoid (20.4%) curvatures. A significant intergroup distribution difference was observed ($p < 0.01$). Post hoc analysis revealed the smartphone group showed: a significantly increased sigmoid curvature ($p < 0.01$) and significantly decreased lordotic ($p < 0.01$) and straight ($p < 0.05$) curvatures compared with controls. However, no significant differences were found in other curvature type ratios (lordotic: straight, lordotic: kyphotic, straight: kyphotic, or kyphotic: sigmoid; all $p > 0.05$).

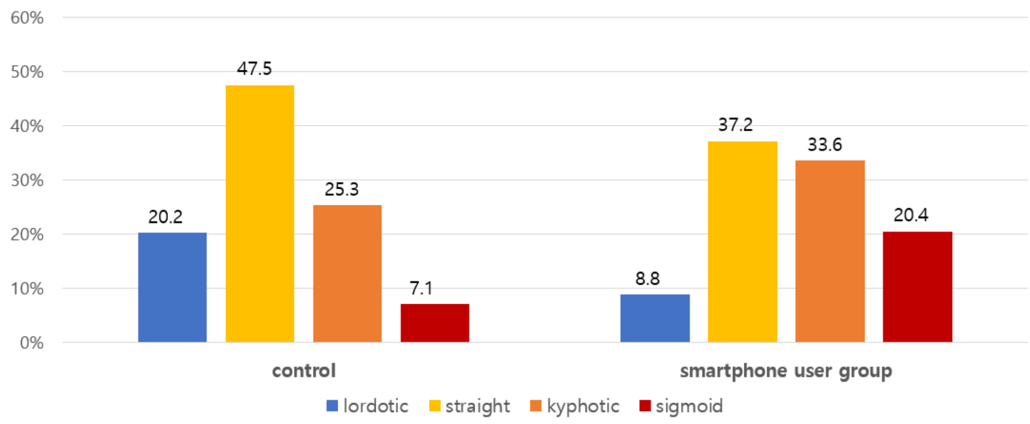
Table II-6. Comparison of cervical curvature type distribution between the control and the smartphone group

Variables	**Lordotic**	**Straight**	**Kyphotic**	**Sigmoid**	***p*-value**†
Control (n= 99)	20 (20.2)	47 (47.5)	25 (25.3)	7 (7.1)	0.006**
Smartphone (n=113)	10 (8.8)	42 (37.2)	38 (33.6)	23 (20.4)	
Post-hoc *p*-value‡		Lordotic vs Straight			> .999
		Lordotic vs Kyphotic			0.197
		Lordotic vs Sigmoid			0.007**
		Straight vs Kyphotic			> .999
		Straight vs Sigmoid			0.035*
		Kyphotic vs Sigmoid			0.584

Data are presented as n (percentage); % symbol omitted.

NS; Not significant, *p< 0.05, **p< 0.01

Figure II-3. Comparison of cervical curvature type distribution between the control and the smartphone group



3.2.3 Distribution of cervical curvature: Comparison between control and smartphone user groups within each vertical facial pattern (Table II-7,8).

In the Hypo group, smartphone users showed reduced lordotic curvature (3.2%) and increased kyphotic curvature (32.3%) compared with the control group (16.7% and 13.3%, respectively). The overall distribution difference was statistically significant ($p < 0.05$; Table II-7); however, post hoc tests showed no significant differences between the individual curvature types ($p > 0.05$). In the Norm and Hyper subgroups, no significant distribution differences were observed between the control and smartphone users ($p > 0.05$; Table II-8).

Table II-7. Comparison of Cervical Curvature Type Distribution Between the Smartphone and Control Groups Within Each Vertical Facial Pattern Subgroup

Variables	**Hypodivergent (n=61)**			**Normovergent (n=84)**			**Hyperdivergent (n=67)**		
	Control (n=29)	Smartphone (n=31)	*p-value*	Control (n=35)	Smartphone (n=48)	*p-value*	Control (n=29)	Smartphone (n=32)	*p-value*
Lordotic	5 (16.7)	1 (3.2)	0.025*	12 (33.3)	5 (10.4)	*NS*	3 (9.1)	4 (11.8)	*NS*
Straight	20 (66.7)	13 (41.9)		10 (27.8)	20 (41.7)		17 (51.5)	9 (26.5)	
Kyphotic	4 (13.3)	10 (32.3)		11 (30.6)	15 (31.3)		10 (30.3)	13 (38.2)	
Sigmoid	1 (3.3)	7 (22.6)		3 (8.3)	8 (16.7)		3 (9.1)	8 (23.5)	

Data are presented as n (percentage); % symbol omitted.

NS; Not significant, $^{*}p < 0.05$

Table II-8. Post-hoc comparison of cervical curvature patterns within Hypodivergent subgroup

	Post-hoc *p*-value‡
Lordotic vs Straight	> .999
Lordotic vs Kyphotic	0.787
Lordotic vs Sigmoid	0.153
Straight vs Kyphotic	0.927
Straight vs Sigmoid	0.275
Kyphotic vs Sigmoid	> .999

4. Discussion

The global increase in smartphone use has raised concerns about posture-related musculoskeletal problems, particularly craniocervical posture and cervical spine alignment.[54,63] However, few studies investigated whether these changes vary by vertical facial pattern.[19-22] In this study, we evaluated how smartphone use affects posture and cervical curvature across different craniofacial types.

4.1 Craniocervical posture

Craniocervical posture was first compared across vertical facial pattern subgroups in smartphone users. The Hyper group showed significantly greater NSL/VER values than the Hypo group, indicating more extended head posture. These findings align with those of previous studies reporting greater head extension in individuals with increased anterior facial height.[14,30,64,65] However, CIA showed no significant differences among facial types, suggesting anteroposterior head translation may not depend solely on vertical skeletal pattern in smartphone users. This contrasts with previous reports linking cervical spine forward inclination with long facial morphology.[14,30,64,65] We propose that habitual smartphone posture may have influenced or attenuated innate skeletal tendencies, creating more uniform head translation across facial types.

Craniocervical posture was compared between the smartphone user and control groups to evaluate smartphone effects. Smartphone users showed significantly lower NSL/VER and CIA values, indicating a forward-downward head posture. This reflects typical smartphone-use posture combining anterior translation and flexion. The greater CIA reduction compared with NSL/VER change suggests that head translation was more pronounced than flexion. This pattern may indicate compensatory head extension to maintain horizontal gaze during cephalometric imaging, where marked flexion is minimized and forward translation remains visible.

To further explore how smartphone use affects each craniofacial group differently, craniocervical posture was compared between smartphone users and controls within each vertical facial pattern subgroup. While NSL/VER values showed no significant subgroup differences, CIA values were significantly reduced across all facial types among smartphone users, with the most pronounced reduction observed in the Hypo group. Both the Hyper and Hypo groups exhibited forward translation; however, the change was greater in the Hypo group. This disproportionate impact might reflect either a greater behavioral susceptibility in the Hypo group, or postural limitations in the Hyper group limiting further anterior displacement. As the Hyper group already exhibited forward head posture before smartphone use, stabilizing mechanisms may have limited further anterior translation.[66] Given that cephalometric imaging is performed in a standing position with a forward gaze, these stabilizers may have normalized posture across vertical facial types. Consequently, the Hypo group (initially less forward head posture), exhibited a greater postural change after smartphone use.

4.2 Cervical curvature

Cervical lordosis represents the physiologic curvature in asymptomatic individuals. In our study, only 9.7% of smartphone users exhibited lordotic curvature. Distribution across vertical facial patterns showed the highest proportion of lordosis in the Norm group (12.5%), followed by the Hyper (9.4%) and Hypo (3.2%) groups, though these differences were not statistically significant. Consequently, 90.3% of participants displayed non-lordotic curvature (straight, kyphotic, or sigmoid types). This prevalence exceeds previously reported rates for asymptomatic populations (26%-72%), which varied by age, sex, and assessment methodology.[3,8,19,32,67-71]

A significant difference in cervical curvature distribution was observed between the smartphone users and control groups ($p < 0.05$). The smartphone group demonstrated markedly higher prevalence of sigmoid curvature along with reduced proportions of lordotic and straight types. When analyzed by vertical facial pattern subgroups, significant intergroup differences emerged only in the Hypo group, while the Norm and Hyper groups showed no statistically significant changes ($p > 0.05$). This finding aligns with the posture analysis findings, where the Hypo group exhibited the most pronounced forward head translation. The curvature changes may reflect compensatory alignment from prolonged anterior head positioning during smartphone use. The Norm group did not reach statistical significance; however, it displayed a clinically notable shift toward non-lordotic patterns. Given that this group initially exhibited the highest proportion of lordosis, the trend may be clinically relevant despite the lack of significance.

The observed increase in sigmoid curvature may reflect postural dynamics during imaging. Prolonged forward head posture during smartphone use typically promotes cervical kyphosis; however, cephalometric acquisition requires participants to maintain a forward gaze while standing, potentially inducing compensatory cervical extension. This extension may modify the cervical spine's radiographic appearance. In cases of mild kyphosis, such compensation could produce a sigmoid curve rather than pure kyphosis. This interpretation is further supported by clinical observations suggesting that compensatory cervical extension in mildly kyphotic individuals can result in a sigmoid appearance on radiographic imaging.[72]

Notably, cervical curvature deterioration was most prominent in the Hypo group, which also showed the greatest forward head translation in posture analysis. This parallel pattern suggests that vertical facial patterns may differently influence responses to sustained anterior head posture. The Hypo group exhibited the most pronounced curvature deterioration; however, this may not necessarily reflect structural susceptibility. Rather, individuals in this group may have been more susceptible to prolonged habitual posture despite initially favorable cervical alignment. Alternatively, extended smartphone use may have attenuated the posture- and curvature-related differences that would normally distinguish vertical skeletal patterns.

Shin et al.'s longitudinal study documented worsening cervical curvature in young adults over the past decade, possibly linked to increasing smartphone dependence.[73] Consistent with this trend, our study showed a higher prevalence of non-lordotic curvature (particularly the sigmoid type) in the smartphone group. Existing literature reports that cervical lordosis tends to decrease more steeply in younger individuals and females—populations exhibiting higher smartphone usage rates.[74-76] Since our study population consisted exclusively of young adult females, these demographic characteristics may have influenced the observed patterns.

These findings highlight the modifying effect of sustained behavioral postures on cervical alignment. They also suggest that innate skeletal tendencies alone cannot fully explain cervical posture and curvature in modern populations.

Detailed clinical implications and limitations of this study are discussed in the General Discussion section.

5. General Discussion

This study explored the effects of vertical facial patterns and smartphone use on craniocervical posture and cervical spine curvature in young adult females. By dividing the research into two parts—Part I focused on skeletal characteristics in the pre-smartphone era, and Part II on behavioral influences from smartphone use—we aimed to distinguish innate skeletal tendencies from environmental adaptations.

The findings from both parts offer several key insights. In Part I, hyperdivergent individuals demonstrated a characteristic forward head posture and reduced cervical lordosis, suggesting that skeletal morphology is associated with altered craniocervical alignment. However, in Part II, posture and curvature changes were observed across all facial types following smartphone use, with the hypodivergent group exhibiting the most pronounced changes. This suggests that habitual posture related to smartphone use may override skeletal predispositions, especially in individuals with initially more neutral alignment.

In addition to behavioral influences such as smartphone use, orthodontic treatment may also be an environmental factor that affects both craniocervical posture and cervical curvature.[77-80] Some studies suggest that interventions like functional appliances or rapid maxillary expansion may influence these parameters, though evidence remains conflicting. As this study excluded patients undergoing active treatment, future research should investigate whether specific orthodontic modalities impact posture or curvature as confounding factors or potential therapeutic options.

While hyperdivergent individuals in Part I exhibited predisposing postural patterns, these were less distinguishable in Part II, implying that behavioral influences—particularly sustained forward head positioning—can homogenize postural profiles. Notably, the cervical inclination angle (CIA) was consistently reduced in smartphone users, indicating significant anterior head translation. The corresponding rise in sigmoid curvature, particularly in the hypodivergent group, supports the hypothesis that postural habits contribute to cervical curvature changes. The increased prevalence of sigmoid curvature underscores the importance of using comprehensive classification methods. In this study, three validated approaches (Ohara, Cobb, and Harrison posterior tangent methods) were employed to assess cervical curvature. This combination allowed detection of subtle or regional deformities, such as sigmoid patterns, which may be missed with angular metrics alone.

5.1 Limitations

This study has several limitations. First, the smartphone and control groups were sampled from different time periods. As current smartphone non-users are rare, potential temporal or secular trends in posture and alignment cannot be excluded. Second, while prolonged smartphone use has been linked to greater postural deterioration, we did not quantify individual usage duration.[12,63,81] However, prior studies have shown that even short-term use (e.g., 10 minutes) can significantly affect posture, supporting the clinical relevance of our findings.[82] Third, the seventh cervical vertebra (C7) was excluded due to frequent invisibility on routine lateral cephalograms, although we mitigated this limitation by applying three validated measurement methods. Finally, our sample was limited to young adult females. Given that age and sex influence cervical posture and curvature, future research should include broader demographic groups.

5.2 Clinical Implications

Craniocervical posture and cervical curvature significantly impact musculoskeletal function, facial aesthetics, and overall quality of life.[83-86] While the underlying mechanisms of cervical alignment changes require further elucidation, our findings underscore the significant influence of behavioral factors, particularly prolonged smartphone use, on craniocervical posture and curvature. These effects appear consistent across vertical skeletal patterns, suggesting that even individuals with initially optimal alignment may develop non-physiologic curvature under sustained postural stress. Given the increasing prevalence of non-lordotic cervical curvature, particularly among young adults with frequent digital device use, clinicians should consider craniocervical posture and cervical spine alignment as part of routine orthodontic assessments. Routine lateral cephalometric radiographs offer a practical means of identifying postural alterations.[87,88] Early detection and intervention is clinically important; therefore, recognizing and addressing these modifiable risk factors may be essential in preventing postural imbalance and maintaining cervical spine health, particularly in younger populations increasingly exposed to digital devices.

Ultimately, this study highlights the need to evaluate both structural and behavioral factors in clinical assessments and supports a preventative approach in managing posture-related cervical spine changes in the digital era.

6. Conclusion

This study investigated the relationship between vertical facial patterns and craniocervical alignment, as well as the influence of prolonged smartphone use on these structural characteristics.

1. In individuals not exposed to habitual smartphone use, the hyperdivergent group demonstrated the most pronounced forward head posture and cervical inclination. A significant association was observed between vertical skeletal pattern and cervical curvature type, with the normovergent group exhibiting the highest prevalence of lordotic curvature.

2. Following widespread smartphone adoption, a shift toward forward and downward head posture was observed across all facial types. While changes were most marked in the hypodivergent group, the difference in craniocervical posture between vertical facial subgroups was not statistically significant. This suggests that sustained behavioral habits may override skeletal tendencies.

3. Cervical curvature patterns changed significantly after smartphone use, with a higher prevalence of non-lordotic forms—particularly sigmoid curvature—compared to the pre-smartphone era. However, facial-type-based differences in curvature were not significant except in the hypodivergent group.

4. These findings indicate that cervical posture and curvature are shaped by both anatomical structure and behavioral influences. Clinicians should consider not only skeletal morphology but also postural habits in orthodontic assessment and cervical spine evaluation.

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국문 요약

수직적 골격 양상에 따른
두경부 자세 및 경추 만곡의 차이
: 스마트폰 상용화 전후 시기의 비교

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장 정 은

본 연구는 수직적 안면 골격 유형에 따른 두경부 자세 및 경추 만곡의 차이를 분석하고, 스마트폰 상용화 전후 시기 간의 변화를 비교하고자 하였다. 연구 대상은 18 세에서 35 세 사이의 성인 여성으로, 스마트폰 상용화 이전 시기의 99 명과 현재 스마트폰을 1 일 1 시간 이상 사용하는 113 명으로 구성되었으며, 모두 골격성 I 급 부정교합자였다. 대상자는 측모 두부 방사선사진에서 측정한 SN-MP 각도를 기준으로 hypodivergent(< 29°), normovergent(31° - 39°), hyperdivergent (> 41°)의 세 군으로 분류하였다. 두경부 자세는 NSL/VER 및 CIA 를 이용하여 평가하였으며, 경추 만곡은 4 가지 유형(lordotic, straight, kyphotic, sigmoid)으로 분류하였다. 통계 분석은 독립표본 t 검정, 일원분산분석 (ANOVA) 및 Tukey 사후검정, Fisher 의 정확 검정, Pearson 상관관계 분석을 사용하여 시행하였다. 주요 결과는 다음과 같다.

1. 스마트폰 상용화 전에는 수직적 안면 골격 유형에 따라 두경부 자세 및 경추 만곡 분포에서 유의한 차이가 있었다.

2. 이 시기 hyperdivergent 군은 가장 전방으로 위치한 두부와 가장 큰 경추 전방 경사도를 보였다.

3. 또한, 수직 골격 유형과 경추 만곡 간 유의한 상관관계가 나타났으며, hyperdivergent 군은 normovergent 군에 비해 lordotic curve 의 비율이 유의하게 낮았다.

4. 스마트폰 상용화 이후에는 수직 골격 유형 간 두경부 자세 및 경추 만곡 분포에서 유의한 차이가 나타나지 않았다.

5. 스마트폰 사용자군은 상용화 전 대상자보다 경추는 전방 기울어지고, 두부는 하방으로 회전된 자세를 보였다.

6. 모든 수직 골격 유형에서 비정상 만곡(non-lordotic curve)의 비율이 증가하였으나, 유형 간 분포 차이는 유의하지 않았다.

7. 이 중에서도 hypodivergent 군에서 두경부 자세 및 경추 만곡의 변화가 가장 두드러지게 관찰되었다.

핵심되는 말: 수직적 안면 골격, 두경부 자세, 경추 만곡, 스마트폰 사용전 시기, 스마트폰 상용화 스마트폰 사용전후 비교