Original Article

Differences in heritability of craniofacial skeletal and dental characteristics between hypo- and hyper-divergent patterns using Falconer's method and principal component analysis

Do-Keun Kim[a]; Joohon Sung[b]; Yun-Mi Song[c]; Eung-Min Kim[d]; Young Ho Kim[e]; Seung-Hak Baek[f]

ABSTRACT

Objectives: To investigate the difference in heritability of craniofacial skeletal and dental characteristics between hypodivergent and hyperdivergent patterns.

Materials and Methods: 53 Korean adult monozygotic (MZ) and dizygotic (DZ) twins and their siblings were divided into a hypodivergent group (Group 1, SN-MP $< 35°$, 17 MZ pairs; 11 DZ and sibling [DS] pairs of the same gender) and hyper-divergent group (Group 2, SN-MP $> 35°$, 16 MZ pairs; 9 DS pairs of the same gender). A total of 56 cephalometric variables were measured using lateral cephalographs. Craniofacial structures were divided into anteroposterior, vertical, dental, mandible, and cranial base characteristics. Falconer's method was used to calculate heritability ($h^2 > 0.8$, high). After principal component analysis (PCA), the mean h^2 value of each component was calculated.

Results: Group 1 exhibited high heritability values in shape and position of the mandible, vertical angular/ratio variables, cranial base shape, and maxillary incisor inclination. Group 2 showed high heritability values in anteroposterior position of the maxilla, intermaxillary relationship, vertical angular variables, cranial base length, and mandibular incisor inclination. Occlusal plane inclination showed high heritability in both groups. Although vertical structure presented a high overall mean h^2 value in Group 1, there were no structures that exhibited a high overall mean h^2 value in Group 2. PCA derived 10 components with 91.2% and 92.7% of cumulative explanation in Groups 1 and 2, respectively.

Conclusions: It is necessary to estimate or predict growth according to vertical pattern for providing differential diagnosis and orthodontic/orthopedic treatment planning. (*Angle Orthod.* 2019;89:242–251.)

KEY WORDS: Heritability; Twins; Falconer's method; Principal components analysis; Vertical pattern

INTRODUCTION

Both genetic and environmental factors can contribute to variations in the size and shape of the craniofacial skeletal and dental structures. If these structures are mainly influenced by genetic factors, orthodontic and/or orthopedic treatment, performed even at an early age, would not significantly change them. On the contrary, if these structures are under control of environmental factors, it would be advantageous to treat the patient from an early age. Therefore,

[a] PhD Student, Department of Orthodontics, School of Dentistry, Seoul National University, Seoul, South Korea.

[b] Professor, Department of Epidemiology, School of Public Health, Seoul National University, Seoul, South Korea.

[c] Professor, Department of Family Medicine, Samsung Medical Center and Center for Clinical Research, Samsung Biomedical Research Institute, Sungkyunkwan University School of Medicine, Seoul, South Korea.

[d] Clinical Assistant Professor, Department of Orthodontics, Institute of Oral Health Science, Ajou University School of Medicine, Suwon, South Korea.

[e] Professor, Department of Orthodontics, Institute of Oral Health Science, Ajou University School of Medicine, Suwon, South Korea.

[f] Professor, Department of Orthodontics, School of Dentistry and Dental Research Institute, Seoul National University, Seoul, South Korea.

Corresponding author: Dr Seung-Hak Baek, Department of Orthodontics, School of Dentistry, Dental Research Institute, Seoul National University, Daehak-no #101, Jongro-gu, Seoul, 03080, Republic of Korea
(e-mail: drwhite@unitel.co.kr)

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Table 1. Demographic Data of the Samples[a,b]

	Group 1 (Hypodivergent group, SN-MP < 35°)	Group 2 (Hyperdivergent group, SN-MP > 35°)	*P* value
Distribution of pairs	17 MZ pairs and 11 DS pairs (3 DZ pairs and 8 SIB pairs)	16 MZ pairs and 9 DS pairs (4 DZ pairs and 5 SIB pairs)	.805
Gender	16 male pairs and 12 female pairs	8 male pairs and 17 female pairs	.066
Age (years)	39.0 ± 9.8	41.3 ± 9.1	.2582
SN-MP (°)	29.2 ± 3.2	41.0 ± 4.3	<.001*

[a] X^2 test and Mann-Whitney U test were performed.

[b] MZ indicates monozygotic twins; DS, dizygotic twins (DZ) and siblings (SIB) of the same-gender; Group 1, hypodivergent group (SN-MP < 35°); Group 2, hyperdivergent group (SN-MP > 35°); * $P < .001$.

it is necessary to verify the degree of genetic and environmental contributions to the characteristics of these structures for appropriate diagnosis and treatment planning.

Cephalometric studies of twins and their families can evaluate the relative contributions of genetic and environment factors on the size and shape of the craniofacial skeletal and dental structures.[1] However, whether vertical traits are more genetically determined than horizontal traits remains controversial. Several previous studies insisted that vertical measurements had greater heritability than horizontal measurements.[2–6] However, other researchers reported that genetic factors might contribute more to horizontal traits compared to vertical traits.[7,8] Heritability estimates should be interpreted with caution because there are possibilities for several types of bias.[9]

Since heritability of the craniofacial characteristics can be influenced by age, sex, ethnicity, and study design, it is necessary to adopt a study design with strict sample selection criteria. For example, the samples should be adult subjects whose growth is completed and who have the same ethnicity and sex. In addition, the samples should be divided according to the vertical and/or horizontal pattern.

Although there are some studies investigating the influence of genetic and environmental factors on the craniofacial phenotype in Korean adult twins and their siblings,[8,10] there are no twin studies comparing the heritability of the craniofacial skeletal and dental characteristics between skeletal hypodivergent and hyperdivergent subjects. Therefore, the purpose of this study was to investigate the differences in heritability of craniofacial skeletal and dental characteristics between hypodivergent and hyperdivergent patterns in monozygotic (MZ) adult twins, dizygotic (DZ) adult twins, and their adult siblings. The null hypothesis was that there was no significant difference in heritability of the craniofacial skeletal and dental characteristics between hypodivergent and hyperdivergent subjects.

MATERIALS AND METHODS

The initial samples consisted of 150 Korean adult twins and their families (36 pairs of MZ twins, 13 pairs of DZ twins, and 26 pairs of their adult siblings), whose lateral cephalometric radiographs were taken in natural head position at Samsung Medical Center, Seoul, South Korea. This twin study protocol was reviewed and approved by the Institutional Review Board of the School of Public Health, Seoul National University, Seoul, South Korea (IRB 2005-08-113-027). Informed consent was obtained from all subjects.

The inclusion criteria were as follows:[8,10] (1) those who did not have an edentulous area of the anterior dental region that could affect the facial profile; (2) those who did not wear a removable prosthesis that could affect the vertical dimension of the face; (3) those who had not undergone orthodontic treatment or orthognathic surgery; (4) those whose growth was complete (over 19 years of age); and (5) those whose gender was the same in the DZ pairs and sibling pairs.

According to the vertical pattern, a total of 53 Korean adult twins and their siblings were allocated into the two groups (criteria: mean value of SN-MP angle of Korean adult twins, 35°; Table 1):[8] Hypodivergent group (Group 1, SN-MP < 35°; mean age, 39.0 years old; 17 MZ pairs; 11 DZ and sibling [DS] pairs [three DZ pairs and eight sibling pairs]) and hyperdivergent group (Group 2, SN-MP > 35°; mean age, 41.3 years old; 16 MZ pairs; 9 DS pairs [four DZ pairs and five sibling pairs]).

The landmarks and reference lines used for cephalometric measurement are illustrated in Figure 1. A total of 56 linear, angular, and ratio cephalometric variables were measured using lateral cephalographs (Figure 2). The craniofacial structures were divided into five areas as follows: anteroposterior (AP), vertical, dental, mandible, and cranial base characteristics.[8] All measurements were performed by a single operator (EK) using the V-Ceph 6.0 program (Cybermed, Seoul, South Korea).

All variables from 20 randomly selected subjects were remeasured by the same operator (EK) at 2-week intervals. The intra-operator measurement error was assessed using the intraclass correlation coefficient (ICC). Since there were no significant differences between the first and second measurements, the first set of measurements was used.

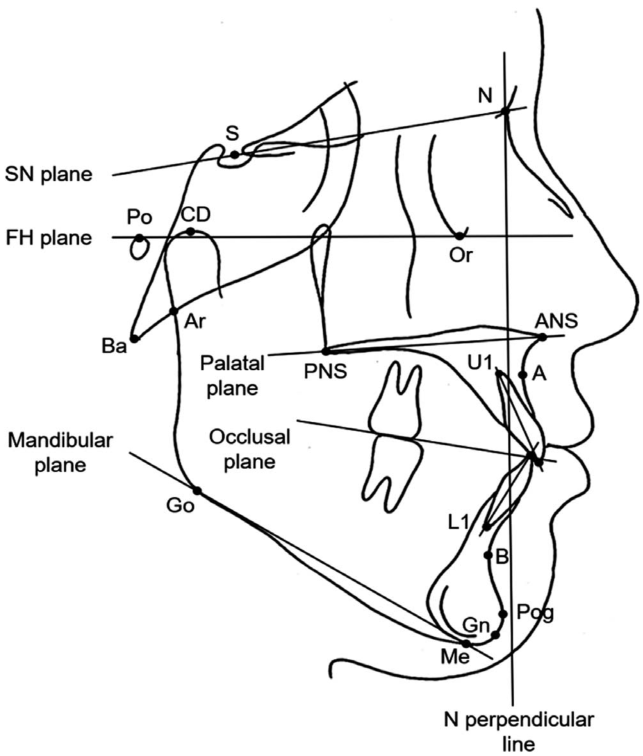

Figure 1. Landmarks and reference lines. Landmarks: S indicates sella; N, nasion; Po, porion; Or, orbitale; CD, condylion; Ar, articulare; Ba, basion; PNS, posterior nasal spine; ANS, anterior nasal spine; A, A point; B, B point; Pog, pogonion; Gn, gnathion; Me, menton; Go, gonion; Reference lines: SN plane; FH (Frankfort Horizontal) plane; Palatal plane (PP); Occlusal plane (OP); Mandibular plane (MP); N perpendicular line; U1, long axis of the upper incisor; L1, long axis of the lower incisor.

Although the genetic effect (A) of the MZ pairs is equal, the DS pairs of the same gender share half of their genetics.[11] On the assumption that the MZ and DS pairs have the same environmental effect (E),[10,12] the Pearson's correlation coefficient (r_{mz}, r_{ds}) was calculated as $r_{mz} = A + E$ and $r_{ds} =$ 1/2 A+E, respectively (Table 2).

Falconer's method has been used to calculate genetic heritability (h^2) based on the difference between the Pearson's correlation coefficients of Groups 1 and 2.[8,11–14] Heritability was calculated as $h^2 = 2$ (r_{mz}- r_{ds}).[8,10,13,14] Cultural inheritance (c^2), which shows the environmental effect, was calculated as $c^2 = 2r_{ds}$-r_{mz}.[8,10,13] In the present study, an h^2 value below 0.2 was considered low heritability and that above 0.8 was, high heritability.[8,10]

Principal component analysis (PCA) with Kaiser normalization varimax rotation was used to extract the dominant components for 56 cephalometric variables in Groups 1 and 2.[6–8,10,15,16] The components with an eigenvalue higher than 1 were selected. The mean ICC values of the cephalometric variables grouped by component were calculated. The heritability (h^2) of components was also calculated in Groups 1 and 2.

All statistical analyses were performed with a significance level of 0.05 using SPSS (version 21, IBM Corp., Armonk, NY, USA).

RESULTS

Genetic Heritability (h^2) in Group 1 (Table 3)

In the AP variables, only three variables depicting the AP position of the mandible exhibited high h^2 values (SNB, 1.13; SN-Pog, 0.90; facial angle, 0.91). However, among the vertical variables, numerous angular variables (ODI, 1.49; SN-PP, 1.53; FH-PP, 1.29; PP-MP, 1.11) and ratio variables (N-ANS/ANS-Me, 1.09; ANS-Me/N-Me, 1.22) exhibited high h^2 values. In the dental variables, high h^2 values were observed in maxillary incisor inclination (U1-SN, 1.16;

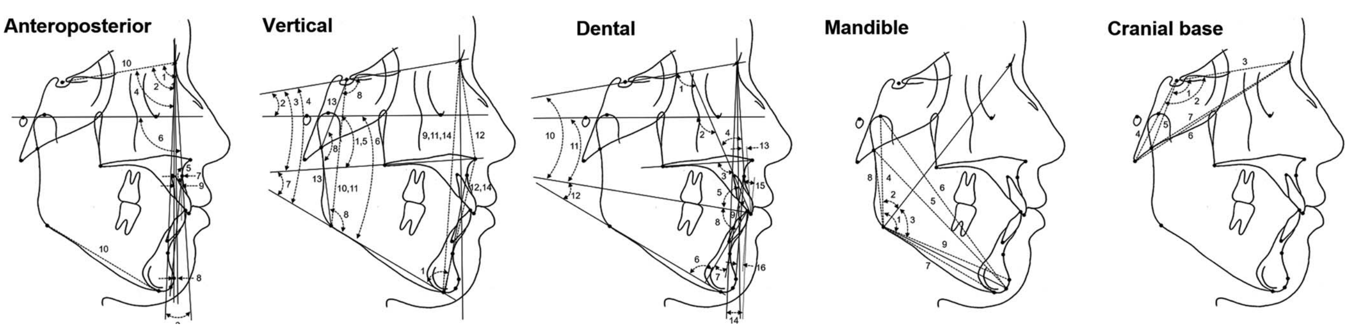

Figure 2. Cephalometric variables. Anteroposterior structure. 1, SNA (°), 2, SNB (°), 3, ANB (°); 4, SN-Pog (°); 5, NA-Pog (°); 6, FH-A (°); 7, A-N perpendicular (mm); 8, Pog-N perpendicular (mm); 9, NPog-A (mm); 10, mandibular body length/anterior cranial base (Go-Me/S-N); Vertical structure. 1, ODI (°) ; 2,SN-FH (°); 3, SN-PP (°); 4, SN-MP (°); 5, FH-PP (°); 6, FMA (°); 7, PP-MP (°); 8, Bjork Sum (°); 9, N-Me (mm); 10, S-Go (mm); 11, S-Go/N-Me; 12, N-ANS/ANS-Me; 13, Posterior cranial base/Ramus height (S-Ar/Ar-Go); 14, ANS-Me/N-Me; Dental structure. 1, U1-SN (°); 2, U1-FH (°); 3, U1-PP (°); 4, U1-NA (angular, °); 5, U1-OP (°); 6, IMPA (°); 7, L1-NB (angular, °); 8, L1-OP (°); 9, Interincisal angle (U1-L1, °); 10, SN-OP (°); 11, FH-OP (°);12, OP-MP (°); 13, U1-NA (linear, mm); 14, L1-NB (linear, mm);15, U1-APog (mm);16, L1-APog (mm); Mandible structure. 1, Gonial angle (Ar-Go-Gn, °); 2, Upper gonial angle (Ar-Go-N, °); 3, Lower gonial angle (N-Go-Gn, °); 4, CD-Go (mm); 5, Ar-Gn (mm); 6, CD-Gn (mm); 7, Go-Me (mm); 8, Ar-Go (mm); 9, Go-Pog (mm); Cranial base structure. 1, Saddle angle (N-S-Ar, °); 2, Cranial base angle (N-S-Ba, °); 3, S-N (mm); 4, S-Ba (mm); 5, S-Ar (mm); 6, N-Ba (mm); 7, Ar-N (mm).

Table 2. The Effects of Genetic and Environmental Factors on the Facial Horizontal, Facial Vertical, Dental, Mandible, and Cranial Base Structures in Groups 1 and 2[a]

Structures	Variables	Group 1 (Hypodivergent group, SN-MP < 35°)		Group 2 (Hyperdivergent group, SN-MP > 35°)	
		r_{mz}	r_{ds}	r_{mz}	r_{ds}
Anteroposterior	SNA (°)	0.7510	0.6113	0.7761	0.1467
	SNB (°)	0.8530	0.2877	0.7010	0.4450
	ANB (°)	0.5370	0.9218	0.7747	0.3655
	SN-Pog (°)	0.8870	0.4356	0.7234	0.5312
	Facial convexity (NA-Pog, °)	0.6000	0.9348	0.8462	0.3188
	Facial angle (FH-NPog, °)	0.7990	0.3425	0.4862	0.3786
	A-N Perpendicular (mm)	0.4170	0.3314	0.3605	0.1101
	Pog-N Perpendicular (mm)	0.8200	0.4431	0.4233	0.4768
	Convexity of A point (NPog-A, mm)	0.6130	0.9368	0.8500	0.3494
	Mandibular body length / Anterior cranial base (Go-Me/S-N)	0.8760	0.6273	0.6546	0.1688
Vertical	ODI (°)	0.8680	0.1236	0.4796	0.0035
	SN-FH (°)	0.7580	0.5485	0.7531	0.3143
	SN-PP (°)	0.9060	0.1404	0.8388	0.0726
	SN-MP (°)	0.6880	0.4658	0.0522	0.4129
	FH-PP (°)	0.8990	0.2543	0.4168	0.5712
	FMA (°)	0.7610	0.3757	0.3367	0.4219
	PP-MP (°)	0.7660	0.2088	0.5531	−0.1544
	Bjork Sum (°)	0.6880	0.4658	0.0522	0.4129
	Ant. Facial Height (AFH, N-Me, mm)	0.9530	0.7691	0.9286	0.5563
	Post. Facial Height (PFH, S-Go, mm)	0.8900	0.6248	0.8983	0.5949
	Facial Height Ratio (S-Go/N-Me)	0.6670	0.2832	0.3861	0.3392
	N-ANS/ANS-Me	0.8630	0.3176	0.8448	0.4982
	Post cranial base/Ramus height (S-Ar/Ar-Go)	0.5560	0.4156	0.7713	0.7286
	ANS-Me/N-Me	0.8590	0.2469	0.8750	0.5642
Dental	U1-SN (°)	0.8960	0.3157	0.4524	0.7589
	U1-FH (°)	0.8820	0.0938	0.4671	0.6586
	U1-PP (°)	0.8760	0.1826	0.4651	0.7073
	U1-NA (angular, °)	0.8120	0.4403	0.6078	0.5797
	U1-OP (°)	0.6960	0.1778	0.1055	0.6762
	IMPA (°)	0.6600	0.6124	0.4492	0.0361
	L1-NB (angular, °)	0.7330	0.8411	0.5548	−0.0332
	L1-OP (°)	0.6610	0.6504	0.4985	−0.4152
	Interincisal angle (°)	0.9010	0.6446	0.5180	0.4810
	SN-OP (°)	0.6640	0.4120	0.4003	0.7388
	FH-OP (°)	0.5980	0.2917	0.7212	0.2153
	OP-MP (°)	0.6020	−0.0448	0.6543	0.2160
	U1-NA (linear, mm)	0.6520	0.1829	0.5928	0.6682
	L1-NB (linear, mm)	0.7880	0.8223	0.8049	0.2333
	U1-APog (mm)	0.8120	0.4855	0.5511	0.7551
	L1-APog (mm)	0.6860	0.4406	0.5289	0.4284
Mandible	Gonial angle (Ar-Go-Gn, °)	0.7110	−0.0274	0.3195	0.5230
	Upper gonial angle (Ar-Go-N, °)	0.6970	0.5739	0.7514	0.4171
	Lower gonial angle (N-Go-Gn, °)	0.7300	0.0297	0.1898	0.5829
	CD-Go (mm)	−0.0080	0.5575	0.8550	0.5521
	Ar-Gn (mm)	0.8730	0.5822	0.9690	0.7833
	CD-Gn (mm)	0.2510	0.6980	0.9467	0.7659
	Go-Me (mm)	0.9070	0.5646	0.7928	0.5566
	Ar-Go (mm)	0.7300	0.4084	0.9201	0.6411
	Go-Pog (mm)	0.7990	0.5632	0.7868	0.5562
Cranial Base	Saddle angle (N-S-Ar, °)	0.7950	0.3704	0.8518	0.6257
	Cranial base angle (N-S-Ba, °)	0.6750	0.7384	0.8179	0.5650
	S-N (mm)	0.8990	0.6089	0.8152	0.1455
	S-Ba (mm)	0.8940	0.8539	0.8382	0.7717
	S-Ar (mm)	0.8690	0.6568	0.7072	0.4913
	N-Ba (mm)	0.9310	0.7369	0.8939	0.5645
	Ar-N (mm)	0.9680	0.6212	0.8968	0.4195

[a] r_{mz}, Pearson's correlation coefficients of the MZ group; r_{ds}, Pearson's correlation coefficients of the DZ and SIB groups.

U1-FH, 1.58; U1-PP, 1.39; U1-OP, 1.04; U1-NA linear, 0.93) and occlusal plane-to-mandibular plane inclination (OP-MP, 1.29). Among the mandible and cranial base variables, high h^2 values were shown in the shape of the mandible and cranial base (gonial angle, 1.48; lower gonial angle, 1.40; saddle angle, 0.85).

Genetic Heritability (h^2) in Group 2 (Table 3)

Among the AP variables, the AP position of the maxilla and intermaxillary relationship exhibited high h^2 values (SNA, 1.26; convexity of A point, 1.00; ANB, 0.82; facial convexity, 1.05). The ratio between mandibular body length and anterior cranial base length also exhibited a high h^2 value (Go-Me/S-N, 0.97). However, in the vertical variables, only four angular variables had high h^2 values (ODI, 0.95; SN-FH, 0.88; SN-PP, 1.53; PP-MP, 1.41). Interestingly, there was no ratio variable with a high h^2 value. In the dental variables, high h^2 values were observed in mandibular incisor inclination (IMPA, 0.83; L1-NB angular, 1.18; L1-NB linear 1.14; L1-OP, 1.83), occlusal plane-to-cranial base inclination (FH-OP, 1.01), and OP-MP (0.88). Among the cranial base variables, cranial base length (Ar-N, 0.95; S-N, 1.34) exhibited a high h^2 value. However, the size and shape of the mandible variables did not show high h^2 values.

Comparison of the Overall Mean h^2 Values for the Five Structures (Table 4)

In Group 1, the overall mean h^2 value was highest at the vertical structure (0.84), followed by the dental structure (0.67), cranial base structure (0.41), mandible structure (0.39), and AP structure (0.26).

However, Group 2 did not include any structure with overall mean h^2 value greater than 0.8. The AP structure exhibited the highest value (0.66), followed by the cranial base structure (0.64), vertical structure (0.41), mandibular structure (0.26), and dental structure (0.21).

Principal Component Analysis (PCA) (Tables 5-8)

In both Groups 1 and 2, the PCA derived 10 components (Tables 5 and 6) with 91.2% and 92.7% of cumulative explanation, respectively (Tables 7 and 8).

In Group 1, three PCA components showed high h^2 values as follows: (1) PCA1 (0.891), which consisted of five vertical variables (SN-MP, Bjork sum, facial height ratio, FMA, PP-MP), one mandibular variable (lower gonial angle), and one dental variable (OP-MP); (2) PCA2 (1.140), which consisted of six dental variables (U1-NA angular, U1-FH, U1-PP, U1 to NA linear, U1-SN, U1-OP); and (3) PCA6 (1.325), which consisted of five vertical variables (SN-PP, N-ANS/ANS-Me, ANS-Me//N-Me, FH-PP, ODI) (Tables 5 and 7).

In Group 2, three PCA components showed high h^2 values as follows: (1) PCA 3 (1.003), which consisted of three AP variables (Convexity of A point, ANB, Facial convexity) and three dental variables (L1-NB angular, L1-NB linear, IMPA); (2) PCA 9 (1.420), which consisted of two dental variables (L1-OP, FH-OP); and (3) PCA10 (1.339), which consisted of anterior cranial base length (S-N) (Tables 6 and 8).

DISCUSSION

Comparison of the Heritability (h^2) between Groups 1 and 2 (Table 3)

Among the vertical facial variables, the angular measurements between the maxilla, mandible, and cranial base exhibited higher heritability values than the linear measurements in both groups (ODI, SN-PP, FH-PP, PP-MP in Group 1; ODI, SN-FH, SN-PP, PP-MP in Group 2). However, the vertical ratio of the anterior facial height had a strong genetic influence in Group 1 only (N-ANS/ANS-Me, ANS-Me/N-Me). These findings indicated that the relative ratio between the upper and lower anterior facial heights might be highly predictable in the hypodivergent pattern, which was similar to the findings of Kim et al.[8] In contrast, Šidlauskas et al.[7] reported low-to-moderate genetic influence in the linear and angular vertical measurements. However, these studies[7,8] did not divide their samples according to the vertical pattern.

Interestingly, posterior facial height (S-Go) and ramus height (CD-Go, Ar-Go) did not show a high heritability in either group. These results suggested that the posterior face height demonstrated a lower genetic determination compared to the anterior face height.[7,17]

Heritability of the AP position of the maxilla and intermaxillary relationship (SNA, convexity of A point, ANB, facial convexity, Go-Me/S-N) showed a strong genetic influence in Group 2. Amini et al.[17] and Kim el al.[8] demonstrated a high heritability of the AP position of the maxilla, but a low-to-moderate heritability of the intermaxillary relationships. This difference might be due to differences in the growth stage or ethnic background of the samples.

The cranial base shape (saddle angle) showed a high heritability in Group 1, while the cranial base length (Ar-N, S-N) showed a high heritability in Group 2. Amini et al.[17] reported a high genetic determination of anterior cranial base length and saddle angle. However, other previous studies[6,8] reported low-to-moderate heritability values for saddle angle and cranial base length. Differences in the results might

Table 3. Genetic Heritability (h^2) and Cultural Inheritance (c^2) of the Facial Horizontal, Facial Vertical, Dental, Mandible, and Cranial Base Structures in Groups 1 and 2

		Group 1 (Hypodivergent group, SN-MP < 35°)		Group 2 (Hyperdivergent group, SN-MP > 35°)	
Structures	Variables	h^2	c^2	h^2	c^2
Anteroposterior	SNA (°)	0.2794	0.4716	1.2588	−0.4827
	SNB (°)	1.1307	−0.2777	0.5120	0.1891
	ANB (°)	−0.7696	1.3066	0.8184	−0.0437
	SN-Pog (°)	0.9027	−0.0157	0.3845	0.3389
	Facial convexity (NA-Pog, °)	−0.6696	1.2696	1.0548	−0.2087
	Facial angle (FH-NPog, °)	0.9130	−0.1140	0.2151	0.2711
	A-N Perpendicular (mm)	0.1712	0.2458	0.5006	−0.1402
	Pog-N Perpendicular (mm)	0.7538	0.0662	−0.1070	0.5303
	Convexity of A point (NPog-A, mm)	−0.6476	1.2606	1.0011	−0.1511
	Mandibular body length/Anterior cranial base (Go-Me/S-N)	0.4974	0.3786	0.9716	−0.3170
Vertical	ODI (°)	1.4889	−0.6209	0.9522	−0.4726
	SN-FH (°)	0.4191	0.3389	0.8776	−0.1245
	SN-PP (°)	1.5312	−0.6252	1.5326	−0.6937
	SN-MP (°)	0.4443	0.2437	−0.7214	0.7736
	FH-PP (°)	1.2895	−0.3905	−0.3088	0.7256
	FMA (°)	0.7706	−0.0096	−0.1704	0.5071
	PP-MP (°)	1.1143	−0.3483	1.4149	−0.8618
	Bjork Sum (°)	0.4443	0.2437	−0.7214	0.7736
	Ant. Facial Height (AFH, N-Me, mm)	0.3677	0.5853	0.7446	0.1839
	Post. Facial Height (PFH, S-Go, mm)	0.5303	0.3597	0.6068	0.2915
	Facial Height Ratio (S-Go/N-Me)	0.7676	−0.1006	0.0939	0.2922
	N-ANS/ANS-Me	1.0909	−0.2279	0.6933	0.1515
	Post cranial base/Ramus height (S-Ar/Ar-Go)	0.2809	0.2751	0.0853	0.6859
	ANS-Me/N-Me	1.2241	−0.3651	0.6215	0.2535
Dental	U1-SN (°)	1.1605	−0.2645	−0.6131	1.0655
	U1-FH (°)	1.5764	−0.6944	−0.3829	0.8500
	U1-PP (°)	1.3868	−0.5108	−0.4846	0.9496
	U1-NA (angular, °)	0.7435	0.0685	0.0563	0.5516
	U1-OP (°)	1.0364	−0.3404	−1.1414	1.2470
	IMPA (°)	0.0952	0.5648	0.8263	−0.3771
	L1-NB (angular, °)	−0.2163	0.9493	1.1759	−0.6212
	L1-OP (°)	0.0212	0.6398	1.8275	−1.3290
	Interincisal angle (°)	0.5127	0.3883	0.0740	0.4440
	SN-OP (°)	0.5041	0.1599	−0.6770	1.0773
	FH-OP (°)	0.6126	−0.0146	1.0119	−0.2907
	OP-MP (°)	1.2937	−0.6917	0.8767	−0.2223
	U1-NA (linear, mm)	0.9381	−0.2861	−0.1507	0.7435
	L1-NB (linear, mm)	−0.0686	0.8566	1.1431	−0.3383
	U1-APog (mm)	0.6530	0.1590	−0.4079	0.9590
	L1-APog (mm)	0.4907	0.1953	0.2009	0.3280
Mandible	Gonial angle (Ar-Go-Gn, °)	1.4768	−0.7658	−0.4069	0.7265
	Upper gonial angle (Ar-Go-N, °)	0.2461	0.4509	0.6687	0.0827
	Lower gonial angle (N-Go-Gn, °)	1.4006	−0.6706	−0.7861	0.9760
	CD-Go (mm)	−1.1310	1.1230	0.6057	0.2493
	Ar-Gn (mm)	0.5815	0.2915	0.3714	0.5976
	CD-Gn (mm)	−0.8941	1.1451	0.3616	0.5851
	Go-Me (mm)	0.6849	0.2221	0.4724	0.3204
	Ar-Go (mm)	0.6432	0.0868	0.5580	0.3621
	Go-Pog (mm)	0.4716	0.3274	0.4612	0.3256
Cranial Base	Saddle angle (N-S-Ar, °)	0.8491	−0.0541	0.4523	0.3995
	Cranial base angle (N-S-Ba, °)	−0.1269	0.8019	0.5057	0.3122
	S-N (mm)	0.5802	0.3188	1.3393	−0.5242
	S-Ba (mm)	0.0801	0.8139	0.1329	0.7053
	S-Ar (mm)	0.4243	0.4447	0.4319	0.2753
	N-Ba (mm)	0.3882	0.5428	0.6589	0.2350
	Ar-N (mm)	0.6937	0.2743	0.9546	−0.0578

Table 4. Comparison of the Overall Mean Values of Genetic Heritability (h^2) and Cultural Inheritance (c^2) for the Facial Horizontal, Facial Vertical, Dental, Mandible, and Cranial Base Structures in Groups 1 and 2

	Group 1 (Hypodivergent group, SN-MP $<$ 35°)		Group 2 (Hyperdivergent group, SN-MP $>$ 35°)	
Structures	h^2	c^2	h^2	c^2
Anteroposterior	0.2561	0.4592	0.6610	−0.0014
Vertical	0.8403	−0.0458	0.4072	0.1776
Dental	0.6713	0.0737	0.2084	0.3148
Mandible	0.3866	0.2456	0.2562	0.4695
Cranial base	0.4127	0.4489	0.6394	0.1922

be due to the inclusion of younger twin samples before completion of growth in previous studies.[6,17]

In the mandible characteristics, although the mandibular body length (Go-Me, Go-Pog), ramus height (CD-Go, Ar-Go), and effective mandibular length (Ar-Gn, CD-Gn) showed low-to-moderate heritability values in both Groups 1 and 2, the shape and position of the mandible (gonial angle, SNB, SN-Pog, facial angle) exhibited high h^2 values only in Group 1. These results were consistent with Amini et al.[17] and Sidlauskas et al.[7], which reported a higher heritability of the shape and position of the mandible than its size. However, Carels et al.[6] reported greater genetic determination for the linear measurements of the mandible compared to the angular measurements of the mandible (gonial angle, SNB). Since the influence of the environmental factors on linear mandibular measurements increased with age,[18] differences in the results might be derived from the growth stage of the samples.

The results from this study showed high heritability values of maxillary incisor inclination (U1-SN, U1-FH, U1-PP, U1-OP, U1-NA linear) in Group 1, and of mandibular incisor inclination (IMPA, L1-NB angular, L1-NB linear, L1-OP) in Group 2. Since Carels et al.[6] and Amini et al.[17] reported high heritability of the dentoalveolar variables including mandibular incisor inclination and vertical position of the molars, the degree of dentoalveolar compensation including dentoalveolar height and incisor inclination might be significantly correlated with genetically determined skeletal parameters.

Comparison of the Overall Mean h^2 Values for the Five Characteristics (Table 4)

The hypodivergent pattern had a strong genetic influence on the vertical structure, while the hyperdivergent pattern did not have strong genetic control over the vertical structures. These findings indicated that genetic control on the vertical structure was more influential in Group 1 than in Group 2.

Principal Component Analysis (PCA) (Tables 5-8)

Component number and cumulative explanation in Groups 1 and 2 were 10 components with 91.2% and 92.7%, respectively. These results were relatively higher than previous twin studies using PCA, which reported five to nine components with 81.0% to 83.0% cumulative explanation.[6,7,19] Differences among these studies might be derived from different study designs and different statistical criteria (ie, eigenvalue) for determining principal components. Furthermore, those studies did not compare the heritability values of each component between hypodivergent and hyperdivergent groups.[6,7,19]

In summary, the results of the present study showed clear differences in the heritability of the craniofacial skeletal and dental characteristics between the hypodivergent and hyperdivergent patterns as follows (Tables 3 to 8): (1) In the vertical jaw position, the hypodivergent pattern had strong genetic influences on both the angular and ratio measurements; whereas the hyperdivergent pattern, only on the angular measurements; (2) In the AP jaw position, the hypodivergent pattern exhibited strong genetic influences only on the AP position of the mandible; while the hyperdivergent pattern, on the AP position of the maxilla and intermaxillary relationships; (3) In the size and shape of the cranial base and mandible, the hypodivergent pattern had a strong genetic influence on the shape of both the cranial base and mandible; whereas the hyperdivergent pattern, only on the cranial base length; (4) In terms of incisor inclination, the hypodivergent patterns exhibited strong genetic influences on maxillary incisor inclination; whereas hyperdivergent pattern, on mandibular incisor inclination; and (5) the occlusal plane inclination exhibited high heritability in both groups.

The results of this study might reveal some clinical implications in growth modification treatment for adolescent patients. In the hypodivergent pattern, growth modification treatment is favorable in changes in mandibular length and/or AP position of the maxilla. In the hyperdivergent pattern, changing the shape and/or size of the mandible is easier compared to changing the AP position of the maxilla. However, individual responses to growth modification treatment could vary even though the structures exhibited low heritability values.

Although heritability estimates of this study might be irrelevant to a different population, the study design and results of this study might be a useful guideline to compare the heritability in different populations. In future studies, three-dimensional analysis with a large

Table 5. Principal Component Analysis (PCA) After Varimax Rotation in Group 1

	PCA1	PCA2	PCA3	PCA4	PCA5	PCA6	PCA7	PCA8	PCA9	PCA10
SN-MP (°)	**0.929**	−0.010	0.173	−0.274	−0.094	0.054	0.032	−0.002	−0.068	0.021
Bjork Sum (°)	**0.929**	−0.010	0.173	−0.274	−0.094	0.054	0.032	−0.002	−0.068	0.021
Facial Height Ratio (S-Go/N-Me)	−**0.900**	−0.046	−0.072	0.235	0.267	−0.011	0.043	0.004	−0.177	−0.068
FMA (°)	**0.885**	−0.039	0.194	0.251	−0.042	0.025	0.109	−0.055	−0.088	−0.239
Lower gonial angle (N-Go-Gn, °)	**0.842**	0.147	0.078	0.193	0.172	−0.099	0.052	−0.134	−0.350	0.046
PP-MP (°)	**0.770**	0.094	0.126	−0.028	−0.089	−0.567	0.093	−0.054	0.009	−0.006
OP-MP (°)	**0.715**	−0.008	0.197	0.264	0.000	−0.062	−0.237	−0.096	0.001	−0.125
U1-NA (angular, °)	−0.049	**0.927**	−0.060	−0.057	−0.025	−0.185	−0.162	−0.169	0.001	−0.025
U1-FH (°)	−0.023	**0.906**	0.104	0.051	−0.004	−0.159	−0.153	−0.067	−0.043	0.286
U1-PP (°)	0.051	**0.884**	0.156	0.239	0.027	0.219	−0.154	−0.073	−0.110	0.152
U1-NA (linear, mm)	0.044	**0.869**	0.007	−0.103	−0.043	−0.306	−0.110	−0.045	0.042	−0.210
U1-SN (°)	−0.024	**0.868**	0.119	0.358	0.025	−0.171	−0.103	−0.098	−0.055	0.124
U1-OP (°)	−0.103	−**0.864**	0.001	−0.144	0.050	0.111	−0.077	−0.052	0.136	−0.058
L1-OP (°)	0.020	−0.171	−**0.890**	0.151	0.149	0.102	0.118	0.087	−0.093	−0.049
L1-NB (angular, °)	0.245	0.264	**0.872**	−0.016	−0.106	−0.042	0.029	−0.021	−0.102	−0.001
IMPA (°)	−0.246	0.173	**0.867**	−0.252	−0.110	−0.011	0.038	−0.060	−0.029	−0.101
L1-NB (linear, mm)	0.404	0.248	**0.823**	0.057	0.112	0.003	0.073	0.094	−0.069	−0.069
Convexity of A point (NPog-A, mm)	0.331	−0.350	**0.765**	0.110	0.045	0.218	0.200	0.062	−0.039	0.174
ANB (°)	0.187	−0.391	**0.764**	0.068	−0.018	0.219	0.249	0.079	−0.062	0.194
Facial convexity (NA-Pog, °)	−0.332	0.349	−**0.761**	−0.121	−0.010	−0.229	−0.189	−0.073	0.041	−0.187
Interincisal angle (°)	−0.168	−0.660	−**0.688**	0.032	0.088	0.097	0.029	0.101	0.079	−0.023
U1-APog (mm)	0.337	0.585	**0.644**	−0.003	−0.020	−0.155	0.050	0.009	0.009	−0.078
L1-APog (mm)	0.494	0.505	**0.524**	0.088	0.080	−0.127	−0.120	0.041	−0.043	−0.197
SNB (°)	−0.081	0.241	−0.141	**0.887**	0.123	−0.143	−0.061	0.086	−0.084	0.197
SN-FH (°)	0.005	0.048	−0.048	−**0.858**	−0.079	0.043	−0.129	0.091	0.037	0.433
SNA (°)	0.047	−0.033	0.361	**0.841**	0.099	0.011	0.104	0.128	−0.116	0.301
SN-Pog (°)	−0.237	0.258	−0.235	**0.840**	0.109	−0.166	−0.041	0.090	−0.093	0.194
Cranial base angle (N-S-Ba, °)	0.010	−0.097	0.056	−**0.733**	0.043	0.225	−0.327	−0.176	−0.038	0.017
Saddle angle (N-S-Ar, °)	−0.098	−0.069	0.197	−**0.661**	0.099	0.355	0.038	−0.327	−0.232	−0.072
Ar-Gn (mm)	−0.049	0.079	−0.149	0.316	**0.851**	0.060	0.098	−0.056	0.256	0.095
Ant. Facial Height (AFH, N-Me, mm)	0.211	−0.146	0.060	0.142	**0.830**	0.035	0.345	0.177	0.155	−0.034
CD-Gn (mm)	0.222	0.137	−0.044	−0.067	**0.820**	−0.014	−0.047	0.066	0.227	0.109
CD-Go (mm)	−0.075	0.054	−0.024	−0.241	**0.810**	−0.032	−0.198	0.126	0.011	0.010
Ar-Go (mm)	−0.505	0.013	−0.132	0.125	**0.790**	0.041	−0.150	−0.046	−0.134	−0.042
Post. Facial Height (PFH, S-Go, mm)	−0.450	−0.131	−0.019	0.252	**0.767**	0.008	0.276	0.138	0.001	−0.068
SN-PP (°)	0.163	−0.145	0.053	−0.327	0.000	**0.867**	−0.087	0.075	−0.104	0.035
N-ANS/ANS-Me	−0.197	−0.190	−0.055	−0.301	0.003	**0.835**	0.045	0.083	0.120	0.071
ANS-Me/N-Me	0.141	0.189	0.047	0.377	0.005	−**0.828**	−0.042	−0.086	−0.135	−0.024
FH-PP (°)	0.154	−0.178	0.090	0.378	0.065	**0.799**	0.021	−0.002	−0.131	−0.316
ODI (°)	−0.438	−0.431	0.406	−0.050	0.033	**0.611**	0.159	0.004	0.007	−0.143
Post. cranial base/Ramus height (S-Ar/Ar-Go)	0.250	−0.182	0.239	0.087	−0.315	−0.034	**0.781**	0.054	0.205	−0.033
S-Ar (mm)	−0.198	−0.206	0.157	0.204	0.417	−0.001	**0.766**	0.028	0.122	−0.097
S-Ba (mm)	−0.154	−0.323	0.057	0.116	0.504	−0.013	**0.638**	0.077	0.163	0.032
Pog-N Perpendicular (mm)	0.404	−0.116	0.119	−0.008	0.128	0.102	**0.409**	0.124	−0.219	−0.249
Upper gonial angle (Ar-Go-N, °)	0.113	0.226	−0.028	−0.106	−0.160	−0.054	0.025	−**0.892**	0.217	−0.040
Mandibular body length / Anterior cranial base (Go-Me/S-N)	0.077	0.002	0.069	0.371	0.116	0.141	0.291	**0.733**	−0.247	0.189
Gonial angle (Ar-Go-Gn, °)	0.603	0.255	0.028	0.042	−0.010	−0.101	0.050	−**0.731**	−0.059	0.000
S-N (mm)	−0.110	−0.080	−0.141	−0.082	0.334	−0.055	−0.002	−0.292	**0.839**	−0.075
N-Ba (mm)	−0.154	−0.261	−0.044	−0.223	0.511	0.025	0.252	−0.212	**0.640**	−0.025
Ar-N (mm)	−0.210	−0.190	0.055	−0.165	0.487	0.076	0.420	−0.300	**0.577**	−0.130
Go-Me (mm)	−0.023	−0.082	−0.047	0.313	0.446	0.086	0.301	0.490	**0.533**	0.140
Go-Pog (mm)	−0.163	−0.097	−0.094	0.334	0.461	0.096	0.247	0.461	**0.519**	0.124
A-N Perpendicular (mm)	0.055	0.000	0.418	0.273	0.079	0.054	0.017	0.249	−0.103	**0.784**
Facial angle (FH-NPog, °)	−0.288	0.367	−0.340	0.163	0.053	−0.160	−0.182	0.204	−0.076	**0.680**
FH-OP (°)	0.197	−0.432	−0.199	0.116	−0.066	0.137	0.405	0.205	−0.121	−**0.456**
SN-OP (°)	0.355	−0.369	−0.143	−0.380	−0.078	0.255	0.074	0.157	−0.175	−**0.389**

Table 6. Principal Component Analysis (PCA) After Varimax Rotation in Group 2

	PCA1	PCA2	PCA3	PCA4	PCA5	PCA6	PCA7	PCA8	PCA9	PCA10
U1-SN (°)	**0.906**	0.165	−0.210	−0.211	−0.101	−0.056	−0.133	0.037	−0.074	0.035
Interincisal angle (°)	−**0.905**	0.023	−0.287	−0.005	−0.016	−0.036	0.052	0.099	0.241	0.061
U1-FH (°)	**0.903**	0.119	−0.276	0.116	−0.073	−0.053	−0.105	0.181	−0.080	0.029
U1-PP (°)	**0.897**	0.211	−0.209	0.026	−0.085	−0.106	0.236	0.031	−0.058	−0.014
U1-NA (angular, °)	**0.882**	0.089	−0.381	0.158	−0.062	−0.053	−0.088	−0.058	−0.088	0.039
U1-NA (linear, mm)	**0.845**	0.187	−0.380	0.065	0.019	0.101	−0.190	−0.077	0.030	0.029
U1-APog (mm)	**0.823**	0.084	0.406	−0.091	0.163	0.009	−0.118	0.004	0.097	0.034
U1-OP (°)	−**0.791**	−0.104	−0.145	0.077	0.083	0.187	−0.029	−0.003	−0.449	0.007
L1-APog (mm)	**0.786**	0.048	0.238	−0.190	0.257	−0.055	−0.171	−0.114	−0.084	−0.007
SN-OP (°)	−**0.495**	−0.111	0.371	0.267	0.322	0.100	0.199	−0.274	0.259	−0.208
Post. Facial Height (PFH, S-Go, mm)	0.090	**0.913**	−0.038	−0.117	−0.282	0.151	−0.066	0.002	0.080	0.052
Ant. Facial Height (AFH, N-Me, mm)	0.076	**0.872**	0.015	0.108	0.287	0.313	−0.026	−0.015	0.070	0.119
CD-Go (mm)	0.175	**0.868**	0.007	−0.152	−0.072	0.069	0.122	0.065	−0.076	−0.154
Ar-Go (mm)	0.136	**0.863**	−0.234	−0.104	−0.301	−0.090	−0.002	−0.060	0.024	0.158
Ar-Gn (mm)	0.145	**0.845**	−0.355	0.005	−0.076	0.162	−0.061	0.150	−0.014	0.212
CD-Gn (mm)	0.216	**0.836**	−0.128	−0.094	0.131	0.252	0.036	0.203	−0.071	−0.031
S-Ar (mm)	−0.018	**0.656**	0.090	0.168	−0.231	0.275	−0.194	0.303	0.091	−0.181
Post cranial base/Ramus height (S-Ar/Ar-Go)	−0.169	−**0.524**	0.342	0.232	0.214	0.267	−0.109	0.289	0.037	−0.266
Convexity of A point (NPog-A, mm)	−0.157	−0.138	**0.901**	−0.185	0.220	−0.080	0.112	−0.041	0.055	0.012
ANB (°)	−0.174	−0.167	**0.890**	−0.189	0.142	−0.051	0.082	−0.045	0.047	−0.041
Facial convexity (NA-Pog, °)	0.167	0.212	−**0.889**	0.192	−0.194	0.098	−0.121	0.026	−0.046	0.002
L1-NB (angular, °)	0.437	−0.104	**0.715**	−0.143	0.063	0.159	0.000	−0.078	−0.323	−0.147
L1-NB (linear, mm)	0.610	0.040	**0.650**	−0.218	0.256	−0.021	−0.082	−0.105	−0.044	−0.022
IMPA (°)	0.404	−0.114	**0.589**	0.119	−0.466	0.156	0.048	−0.153	−0.338	−0.103
SN-FH (°)	−0.064	−0.130	−0.158	**0.862**	0.079	0.013	0.081	0.373	−0.009	−0.017
SNA (°)	−0.045	0.159	0.424	−**0.842**	−0.080	−0.002	−0.089	0.216	0.041	−0.012
SNB (°)	0.074	0.304	−0.155	−**0.833**	−0.195	0.035	−0.162	0.282	0.013	0.016
Cranial base angle (N-S-Ba, °)	−0.073	0.057	−0.387	**0.807**	−0.154	−0.059	0.121	0.095	0.034	0.147
SN-Pog (°)	0.066	0.337	−0.263	−**0.778**	−0.265	0.084	−0.171	0.286	0.003	0.004
Saddle angle(N-S-Ar, °)	0.023	0.149	−0.348	**0.757**	−0.262	−0.123	0.029	0.141	−0.113	0.012
Ar-N (mm)	0.059	0.542	−0.179	**0.657**	−0.297	0.070	−0.017	0.127	−0.030	0.272
N-Ba (mm)	−0.012	0.438	−0.176	**0.585**	−0.149	0.239	0.057	−0.038	0.094	0.548
Bjork Sum (°)	−0.057	−0.189	0.211	0.225	**0.918**	−0.040	0.045	−0.080	0.053	−0.060
SN-MP (°)	−0.057	−0.189	0.211	0.225	**0.918**	−0.040	0.045	−0.080	0.053	−0.060
Lower gonial angle (N-Go-Gn, °)	0.043	0.220	0.145	−0.295	**0.826**	−0.285	−0.072	0.001	0.135	−0.099
FMA (°)	−0.013	−0.092	0.300	−0.349	**0.807**	−0.046	−0.011	−0.316	0.055	−0.045
PP-MP (°)	0.039	−0.219	0.164	−0.181	**0.764**	0.036	−0.532	−0.059	0.015	0.026
Facial Height Ratio (S-Go/N-Me)	0.059	0.503	−0.071	−0.308	−**0.761**	−0.077	−0.078	0.007	0.055	−0.066
OP-MP (°)	0.142	0.029	−0.155	−0.146	**0.754**	0.091	−0.067	−0.117	−0.463	−0.062
Mandibular body length/Anterior cranial base (Go-Me/S-N)	−0.052	0.219	−0.190	−0.194	0.058	**0.799**	−0.134	0.268	−0.075	−0.240
Go-Me (mm)	0.017	0.431	−0.262	0.100	−0.056	**0.773**	−0.065	0.176	−0.092	0.153
Go-Pog (mm)	−0.012	0.439	−0.202	0.127	−0.136	**0.758**	−0.019	0.169	−0.105	0.195
Gonial angle (Ar-Go-Gn, °)	0.152	0.095	−0.197	−0.012	0.504	−**0.741**	−0.126	0.236	0.058	0.042
Upper gonial angle (Ar-Go-N, °)	0.156	−0.094	−0.401	0.277	−0.159	−**0.686**	−0.094	0.307	−0.059	0.152
S-Ba (mm)	−0.086	0.428	0.108	−0.059	0.011	**0.564**	−0.096	−0.030	0.215	0.292
FH-PP (°)	−0.077	0.209	0.174	−0.218	−0.022	−0.120	**0.806**	−0.365	0.052	−0.102
SN-PP (°)	−0.124	0.079	0.028	0.527	0.046	−0.099	**0.799**	−0.017	0.043	−0.108
N-ANS/ANS-Me	−0.243	−0.297	0.073	0.363	−0.114	0.124	**0.722**	0.131	−0.009	0.263
ANS-Me//N-Me	0.239	0.324	−0.109	−0.467	0.045	−0.064	−**0.696**	−0.052	0.016	−0.231
ODI (°)	−0.166	−0.013	0.474	0.072	−0.525	−0.076	**0.580**	−0.279	−0.005	−0.020
A-N Perpendicular (mm)	−0.150	0.064	0.461	−0.177	−0.024	−0.010	−0.035	**0.829**	0.052	−0.028
Pog-N Perpendicular (mm)	−0.053	−0.175	0.462	−0.060	0.243	−0.074	0.084	−**0.787**	0.041	0.051
Facial angle (FH-NPog, °)	0.005	0.251	−0.487	0.053	−0.223	0.113	−0.111	**0.757**	−0.007	−0.015
L1-OP (°)	−0.569	0.086	−0.381	−0.113	0.104	−0.014	−0.005	0.039	**0.659**	−0.014
FH-OP (°)	−0.493	−0.065	0.497	−0.223	0.023	−0.097	0.165	−0.239	**0.508**	−0.045
S-N (mm)	0.133	0.380	−0.132	0.496	−0.177	0.001	0.113	−0.132	−0.049	**0.657**

Table 7. The Pearson's Correlation Coefficients (r) and Heritability (h^2) for Each Principal Component in Group 1[a]

Principal Components	Variance Explained (%)	Cumulative Percentage (%)	r_{mz}	r_{ds}	h^2 (Group 1)
PCA1	14.355	14.355	0.700	0.255	0.891
PCA2	13.906	28.261	0.802	0.232	1.140
PCA3	12.635	40.896	0.699	0.729	-0.060
PCA4	10.983	51.879	0.787	0.499	0.576
PCA5	10.437	62.316	0.615	0.607	0.016
PCA6	7.782	70.099	0.879	0.217	1.325
PCA7	5.827	75.926	0.785	0.592	0.385
PCA8	5.612	81.537	0.761	0.391	0.740
PCA9	5.103	86.641	0.901	0.619	0.564
PCA10	4.526	91.167	0.620	0.344	0.550

[a] $h^2_{(Group\ 1)} = 2\ (r_{mz} - r_{ds})$; r_{mz}, Pearson's correlation coefficients of the MZ group; r_{ds}, Pearson's correlation coefficients of the DS group.

Table 8. The Pearson's Correlation Coefficients (r) and Heritability (h^2) for Each Principal Component in Group 2[a]

Principal Components	Variance Explained (%)	Cumulative Percentage (%)	r_{mz}	r_{ds}	h^2 (Group 2)
PCA1	15.679	15.679	0.469	0.645	-0.353
PCA2	13.939	29.618	0.875	0.639	0.471
PCA3	13.407	43.025	0.713	0.212	1.003
PCA4	12.369	55.394	0.802	0.451	0.701
PCA5	12.191	67.585	0.318	0.319	-0.002
PCA6	7.030	74.615	0.691	0.499	0.383
PCA7	6.198	80.814	0.691	0.342	0.698
PCA8	6.122	86.936	0.423	0.322	0.203
PCA9	2.999	89.935	0.610	-0.100	1.420
PCA10	2.747	92.681	0.815	0.145	1.339

[a] $h^2_{(Group\ 2)} = 2\ (r_{mz} - r_{ds})$; r_{mz}, Pearson's correlation coefficients of the MZ group; r_{ds}, Pearson's correlation coefficients of the DS group.

sample size is necessary to investigate the heritability of transverse characteristics.

CONCLUSIONS

- The null hypothesis was rejected.
- Since the hypodivergent and hyperdivergent subjects exhibited different degrees of genetic influences on the AP/vertical position of the maxilla and mandible, shape of the mandible, incisor inclination, and shape and length of the cranial base, it is necessary to estimate or predict growth according to the vertical pattern for providing differential diagnosis and orthodontic/orthopedic treatment planning.

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