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Differences in the heritability of craniofacial skeletal and dental characteristics between twin pairs with skeletal Class I and II malocclusions

Heon-Mook Park[a]
Pil-Jong Kim[b]
Joohon Sung[c]
Yun-Mi Song[d]
Hong-Gee Kim[b]
Young Ho Kim[e]
Seung-Hak Baek[f]

[a]Department of Orthodontics, School of Dentistry, Seoul National University, Seoul, Korea

[b]Biomedical Knowledge Engineering Laboratory, School of Dentistry, Seoul National University, Seoul, Korea

[c]Department of Epidemiology, School of Public Health, Seoul National University, Seoul, Korea

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

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

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

Objective: To investigate differences in the heritability of skeletodental characteristics between twin pairs with skeletal Class I and Class II malocclusions. **Methods:** Forty Korean adult twin pairs were divided into Class I (C-I) group (0° ≤ angle between point A, nasion, and point B [ANB]) ≤ 4°; mean age, 40.7 years) and Class II (C-II) group (ANB > 4°; mean age, 43.0 years). Each group comprised 14 monozygotic and 6 dizygotic twin pairs. Thirty-three cephalometric variables were measured using lateral cephalograms and were categorized as the anteroposterior, vertical, dental, mandible, and cranial base characteristics. The ACE model was used to calculate heritability (A > 0.7, high heritability). Thereafter, principal component analysis (PCA) was performed. **Results:** Twin pairs in C-I group exhibited high heritability values in the facial anteroposterior characteristics, inclination of the maxillary and mandibular incisors, mandibular body length, and cranial base angles. Twin pairs in C-II group showed high heritability values in vertical facial height, ramus height, effective mandibular length, and cranial base length. PCA extracted eight components with 88.3% in the C-I group and seven components with 91.0% cumulative explanation in the C-II group. **Conclusions:** Differences in the heritability of skeletodental characteristics between twin pairs with skeletal Class I and II malocclusions might provide valuable information for growth prediction and treatment planning.
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Key words: Heritability, Twins, ACE model, Principal component analysis

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INTRODUCTION

When predicting growth and planning orthodontic and/or orthopedic treatments in growing patients, clinicians must consider diverse craniofacial skeletal and dental characteristics. Several growth prediction methods have provided information on whether orthodontic and/or orthopedic treatments can be applied or should be delayed until the completion of growth by using patient or population-based cephalometric data.[1-8] In particular, Ricketts[1,2,4] studied several cephalometric growth prediction methods to determine mandibular growth. Barbosa et al.[8] also compared longitudinal growth changes between patients with Class I and Class II division 2 malocclusions by using lateral cephalograms. However, the influences of genetic and environmental factors on skeletal, dental, and soft tissue characteristics cannot be completely investigated using simple cephalometric analysis. Therefore, genetic analyses have been performed using parent-offspring correlation, model fitting, questionnaire with pedigree chart, and twin model studies.[2-7]

Monozygotic (MZ) twins share identical genetic information, whereas dizygotic (DZ) twins share only half of their genetic information. Therefore, genetic differences between MZ and DZ twins can be determined under an assumption of identical environments for the MZ and DZ twins. Classical twin study designs, including the ACE model and Falconer's formula, are useful for examining the effects of genetic and environmental variances on phenotypic expression.[9-11] Therefore, numerous twin studies[12-22] have included both MZ and DZ twins.

The capability of twin studies to accurately analyze the effects of genetic and environmental factors on the sizes and shapes of craniofacial structures has been utilized by numerous previous studies.[12-22] Nevertheless, several factors must be considered when designing the twin studies. First, the degree of heritability estimates can be influenced by the age of the subjects. If the subjects are adolescents, their mandibular growth will continue until the completion of growth. Therefore, twin pairs under the age of 19 years should be excluded to minimize the influence of age. Second, the sex of DZ twin pairs should be matched to minimize errors arising from the differences in cephalometric linear and angular variables between males and females.[20-22]

Although some studies have investigated the influences of genetic and environmental factors on craniofacial morphology using adult twins,[20-22] no twin study to date compared the craniofacial skeletal and dental characteristics between twin pairs with skeletal Class I and Class II malocclusions. Therefore, the purpose of this study was to investigate the differences in the heritability of craniofacial skeletal and dental characteristics between MZ and DZ twin pairs with skeletal Class I and Class II malocclusions.

MATERIALS AND METHODS

The initial sample included 126 Korean adult twins (48 MZ and 15 DZ twin pairs) whose lateral cephalograms were available at the Samsung Medical Center, Seoul, Republic of Korea. The study protocol was reviewed and approved by the Institutional Review Board of the School of Public Health, Seoul National University, Seoul, Republic of Korea (IRB 2005-08-113-027). Informed consent was obtained from all subjects.

The inclusion criteria were as follows: (1) MZ or DZ twin pairs, (2) DZ twin pairs with the same sex, (3) age over 19 years, and (4) a skeletal Class I or Class II pattern (angle between point A, nasion, and point B [ANB] > 0°). These criteria were employed to avoid any bias from age and sex.[20-22]

The exclusion criteria were as follows: (1) an edentulous area of the anterior teeth, (2) use of a removable prosthesis, and (3) a history of orthodontic treatment or orthognathic surgery. These criteria were employed to avoid the influences of these conditions on the profile and vertical dimension of the face.[20-22]

As the final sample, 40 Korean adult MZ and DZ twin pairs (mean age, 41.9 ± 8.3 years; 40 males and 40 females) were selected. They were divided into the Class I group (n = 20 twin pairs; $0° \leq ANB \leq 4°$; mean age, 40.7 ± 7.4 years) and the Class II group (n = 20 twin pairs; ANB > 4°; mean age, 43.0 ± 9.0 years). Each group comprised 14 MZ and 6 DZ twin pairs with the same sex (20 males and 20 females per group; Table 1).

The landmarks and reference lines used for cephalometric analysis are illustrated in Figure 1. The craniofacial characteristics were categorized into the anteroposterior (AP), vertical, dental, mandibular and cranial base characteristics for investigating the areas influenced by heredity.[20-22] The linear, angular, and ratio variables, which could describe the sizes and shapes of these structures (Figure 2), were measured by a single operator (EMK) using the V-Ceph 6.0 program (Cybermed, Seoul, Korea). Since overbite depth indicator showed significant differences between the MZ and DZ twin subgroups ($p <$ 0.01 in the Class I group, $p <$ 0.05 in the Class II group) and lower gonial angle showed significant differences between the MZ and DZ twin subgroups ($p <$ 0.05 in the Class I group; Table 2), these variables were excluded. Finally, 33 cephalometric variables were selected for further investigation (Table 2).

All variables from 20 randomly selected subjects were remeasured by the same operator (EMK) after a 2-week interval. The intra-operator measurement error was assessed using the intraclass correlation coefficient (ICC). Since no significant differences were observed between

Table 1. Demographic data of samples

Variable	Class I group	Class II group	Significance
Distribution of pairs	14 MZ pairs and 6 DZ pairs	14 MZ pairs and 6 DZ pairs	1.0000
Sex	20 males and 20 females	20 males and 20 females	1.0000
Age (yr)	40.71 ± 7.36	43.02 ± 9.03	0.2582
ANB (°)	2.10 ± 1.26	5.04 ± 1.47	0.0001***

Values are presented as mean ± standard deviation.
Chi-square test and Mann–Whitney U test were performed.
ANB, angle between point A, nasion, and point B; MZ, monozygotic twin; DZ, dizygotic twin.
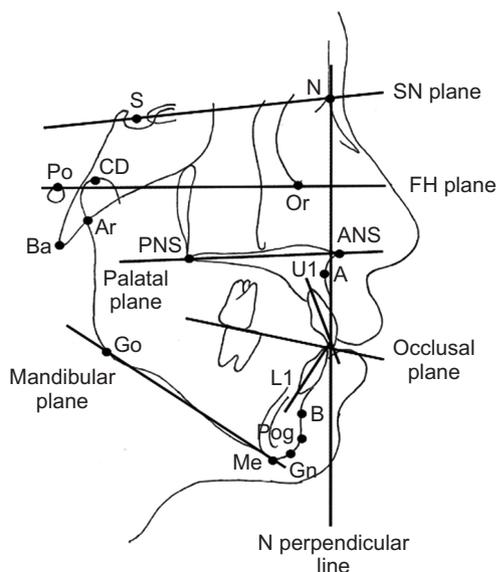***$p < 0.001$.

Figure 1. Landmarks and reference lines used in the cephalometric analysis.
Landmarks: S, 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; Frankfort-horizontal (FH) 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.

the first and second measurements, the first set of measurements was used for anlaysis.

The genetic effect (A) on MZ twins is equal because they have identical genetic information; however, DZ twins with the same sex share only half of their genetic information. In addition, both MZ and DZ twins are assumed to have the same environmental effect (E).[20-24] Therefore, Pearson's correlation coefficients (r_{mz}, r_{dz}), i.e., the sum of the genetic and environmental effects on the phenotype, were calculated as follows: $r_{mz} = A + E$ in MZ twin pairs and $r_{dz} = \frac{1}{2} / A + E$ in DZ twin pairs (Table 3).

Based on the difference between the correlation coefficients for MZ twin pairs and DZ twin pairs with the same sex, the ACE model was used to calculate the additive genetic effects (A), common environmental effects (C), and specific environmental effects (E).[20] This provided information about the heritability (A) of twins.[23] In the present study, an A value above 0.7 was considered to indicate high heritability and an A value between 0.4 and 0.7 was considered to indicate moderate heritability.

Principal component analysis (PCA) with Kaiser normalization varimax rotation was used to extract components by grouping the cephalometric variables in the Class I and Class II groups.[21,22,25] The components with an eigenvalue higher than 1 were chosen.[18,19] After the mean ICC values of each component were calculated, the A value was also calculated for the Class I and Class II groups.[21,22]

All statistical analyses were performed using SPSS program version 21.0 (IBM Corp., Armonk, NY, USA). A p-value less than 0.05 was considered statistically significant.

RESULTS

Genetic heritability (A) in the Class I group (Table 4)

Among the AP characteristics, the maxilla, mandible, and intermaxillary relationship showed high A values (SNA, 0.80; SNB, 0.86; facial convexity angle, 0.74; facial angle, 0.74; Pog-N perpendicular, 0.84; and Go-Me/S-N, 0.70). Among the vertical characteristics, two angular variables showed high A values (FH-PP, 0.74; PP-MP, 0.74). Among the dental characteristics, the inclination of the maxillary and mandibular incisors and interincisal angle showed high A values (U1-FH, 0.82; U1-PP, 0.73; IMPA, 0.87; and interincisal angle, 0.75). Among the mandibular characteristics, only mandibular body length showed a high A value (Go-Me, 0.75). Among the cranial base characteristics, cranial base angle showed a high A value (N-S-Ba, 0.86).
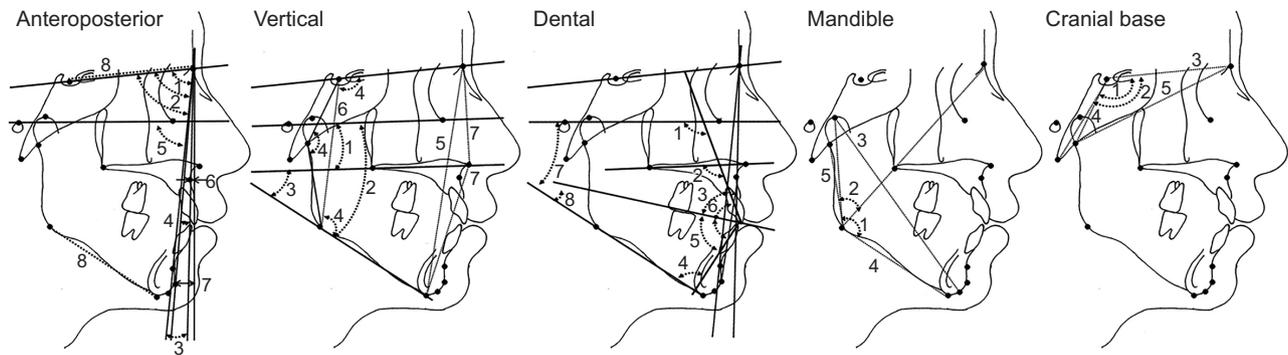
Figure 2. Cephalometric variables.
Anteroposterior characteristics: 1, SNA (angle between S, N, and point A); 2, SNB (angle between S, N, and point B); 3, ANB (angle between point A, N, and point B); 4, NA–Pog (angle between N, point A, and Pog); 5, FH–NPog (angle formed by FH plane and N–Pog line); 6, A–N perpendicular (perpendicular distance from point A to the N perpendicular line); 7, Pog–N perpendicular (perpendicular distance from Pog to the N perpendicular line); and 8, mandibular body length/anterior cranial base (ratio of the distance between Go and Me to the distance between S and N). Vertical characteristics: 1, FH–PP (angle formed by FH plane and palatal plane); 2, FMA (angle formed by FH plane and mandibular plane); 3, PP–MP (angle formed by PP and MP); 4, Bjork sum (summation of angles determined by saddle angle, articular angle, and gonial angle); 5, N–Me (distance between N and Me); 6, S–Go (distance between S and Go); and 7, N–ANS/ANS–Me (ratio of the distance between N and ANS to the distance between ANS and Me). Dental characteristics: 1, U1–FH (angle formed by upper incisor axis and FH plane); 2, U1–PP (angle formed by U1 and PP); 3, U1–OP (angle formed by U1 and OP); 4, IMPA (angle formed by lower incisor axis and MP); 5, L1–OP (angle formed by L1 and OP); 6, interincisal angle (angle formed by U1 and L1); 7, FH–OP (angle formed by FH plane and OP); and 8, OP–MP (angle formed by OP and MP). Mandible characteristics: 1, gonial angle (angle between Ar, Go, and Me); 2, upper gonial angle (angle between Ar, Go, and N); 3, CD–Gn (distance between condyle head and Gn); 4, Go–Me (distance between Go and Me); and 5, Ar–Go (distance between Ar and Go). Cranial base characteristics: 1, saddle angle (angle between N, S, and Ar); 2, cranial base angle (angle between N, S, and Ba); 3, S–N (distance between S and N); 4, S–Ar (distance between S and Ar); and 5, Ar–N (distance between Ar and N).
See Figure 1 for definition of each landmark.

Genetic heritability (A) in the Class II group (Table 4)

Among the AP characteristics, only two variables showed high A values (SNB, 0.89 and facial angle, 0.80). Among the vertical characteristics, PP–MP and facial height variables showed high A values (PP–MP, 0.84; anterior facial height, 0.93; and posterior facial height, 0.92). Among the mandibular characteristics, two variables showed high A values (CD–Gn, 0.74 and Ar–Go, 0.81). Among the cranial base characteristics, three variables showed high A values (S–N, 0.84; S–Ar, 0.80; and Ar–N, 0.90). However, none of the dental variables showed high A values.

Comparison of A values between the Class I and Class II groups (Table 4)

Among AP and vertical characteristics, SNB, facial angle, and PP–MP showed high heritability in the two groups. However, none of the dental, mandibular, and cranial base characteristics showed high heritability in the two groups.

PCA in the Class I group (Table 5)

PCA extracted eight components with 88.3% cumulative explanation. Among these eight components, PCA2 and PCA6 had three variables with high A values (U1–PP, U1–FH, and facial angle in PCA2; Go–Me/S–N, Go–Me, and Pog–N perpendicular in PCA6). In addition, PCA4 and PCA5 had two variables with high A values (cranial base angle and SNB in PCA4; IMPA and interincisal angle in PCA5).

PCA in the Class II group (Table 6)

PCA extracted seven components with 91.0% cumulative explanation. Among these seven components, PCA1 had seven variables with high A values (anterior facial height, S–N, S–Ar, Ar–Go, CD–Gn, posterior facial height, and Ar–N). PCA2 had two variables with high A values (facial angle and PP–MP).

DISCUSSION

This twin study was the first to compare the herita-

Table 2. Comparison of cephalometric variables measured between the monozygotic (MZ) and dizygotic (DZ) twin subgroups within Class I and Class II groups

Cephalometric variable		Class I group					Class II group				
		Class I-DZ (n = 6 pairs)		Class I-MZ (n = 14 pairs)		p-value	Class II-DZ (n = 6 pairs)		Class II-MZ (n = 14 pairs)		p-value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Antero-posterior	SNA (°)	80.43	2.52	81.16	3.91	0.5354	83.96	4.40	81.45	3.00	0.1023
	SNB (°)	78.51	3.01	78.99	3.70	0.6687	78.81	4.47	76.47	2.89	0.1365
	ANB (°)	1.94	1.57	2.17	1.13	0.7454	5.16	1.40	4.99	1.51	0.5710
	Facial convexity angle (NA-Pog, °)	177.86	6.74	177.40	3.68	0.9647	170.16	3.85	170.67	3.42	0.6542
	Facial angle (FH-NPog, °)	89.25	3.14	88.56	2.71	0.3301	87.21	2.10	86.66	2.33	0.1200
	A-N perpendicular (mm)	0.36	2.54	-0.20	3.01	0.3525	2.01	1.63	1.18	2.45	0.1023
	Pog-N perpendicular (mm)	4.45	4.73	5.09	3.30	0.2814	6.34	2.92	7.21	3.71	0.1509
	Mandibular body length/ anterior cranial base (Go-Me/S-N)	1.16	0.09	1.13	0.08	0.4517	1.10	0.10	1.10	0.06	0.8536
Vertical	ODI	67.02	6.76	73.14	3.59	0.0048**	74.71	5.96	77.17	5.32	0.0362*
	FH-PP (°)	0.07	3.46	1.08	2.58	0.4517	1.28	3.74	1.59	2.31	0.6829
	FMA (°)	27.11	3.82	23.62	4.97	0.0570	27.06	5.49	25.82	5.66	0.3917
	PP-MP (°)	25.36	4.91	22.55	4.41	0.1213	25.78	5.54	24.22	6.42	0.2204
	Bjork sum (°)	395.33	2.56	392.27	5.62	0.0954	395.07	6.80	395.43	5.99	0.7419
	Anterior facial height (AFH, N-Me, mm)	122.34	4.90	120.66	6.21	0.3375	120.53	5.90	121.61	7.18	0.5532
	Posterior facial height (PFH, S-Go, mm)	80.52	4.76	82.59	8.47	0.6263	80.80	6.16	80.73	7.87	0.6637
	N-ANS/ANS-Me	0.78	0.07	0.81	0.05	0.1481	0.79	0.06	0.85	0.09	0.0561
Dental	U1-FH (°)	116.64	6.63	113.25	6.35	0.0570	114.19	5.51	111.79	6.81	0.2012
	U1-PP (°)	118.38	7.91	114.33	6.42	0.0742	115.47	5.87	113.40	6.49	0.3991
	U1-OP (°)	54.20	3.94	55.74	4.99	0.1793	54.26	6.75	56.30	6.02	0.2517
	IMPA (°)	92.98	7.57	97.02	7.59	0.1213	100.19	5.98	100.57	5.92	0.4686
	L1-OP (°)	67.91	6.34	68.25	8.51	0.5257	61.65	5.66	63.03	7.60	0.8228
	Interincisal angle (°)	121.60	10.05	126.11	11.05	0.1891	118.57	10.02	121.81	11.43	0.5016
	FH-OP (°)	9.16	4.83	11.01	3.09	0.0514	11.56	4.30	11.90	5.15	0.7419
	OP-MP (°)	16.83	4.16	13.77	5.16	0.0742	16.20	3.39	14.29	5.27	0.1665

Table 2. Continued

Cephalometric variable		Class I group					Class II group				
		Class I-DZ (n = 6 pairs)		Class I-MZ (n = 14 pairs)		p-value	Class II-DZ (n = 6 pairs)		Class II-MZ (n = 14 pairs)		p-value
		Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Mandible	Gonial angle (Ar-Go-Gn, °)	122.38	8.79	118.45	7.51	0.2097	121.11	8.02	119.33	5.59	0.2409
	Upper gonial angle (Ar-Go-N, °)	44.46	4.26	44.91	3.90	0.8943	43.87	4.61	44.06	2.31	0.6829
	Lower gonial angle (°)	77.92	5.00	73.54	4.43	0.0126*	77.23	5.80	75.26	4.85	0.1232
	CD-Gn (mm)	108.62	8.34	107.44	8.53	0.7566	103.28	8.43	104.89	9.45	0.4768
	Go-Me (mm)	73.74	3.96	72.98	5.61	0.5851	69.23	5.67	70.80	4.65	0.4850
	Ar-Go (mm)	48.01	5.20	50.67	7.06	0.1992	47.44	4.78	48.56	6.36	0.2979
Cranial base	Saddle angle (N-S-Ar, °)	126.95	4.13	127.34	5.32	0.8479	123.72	3.16	125.89	4.14	0.0820
	Cranial base angle (N-S-Ba, °)	133.64	4.03	133.56	4.78	0.7343	131.58	5.10	133.07	3.57	0.4216
	S-N (mm)	62.23	3.37	64.61	2.45	0.1523	62.97	3.35	64.25	3.37	0.1547
	S-Ar (mm)	35.91	2.99	35.74	3.26	0.6159	35.98	2.98	35.41	3.41	0.8023
	Ar-N (mm)	89.22	4.50	90.80	4.55	0.2097	87.70	4.39	90.44	5.15	0.0546

Mann–Whitney U test was performed to compare the variables between the MZ and DZ subgroups within the Class I and Class II groups.

SD, standard deviation; ODI, overbite depth indicator.

*p < 0.05, **p < 0.01.

See Figure 1 and 2 for definition of each landmark or measurement.

bility of craniofacial skeletal and dental characteristics between twin pairs with skeletal Class I and Class II malocclusions. In previous studies, craniofacial skeletal and dental characteristics were analyzed without considering the differences in the AP skeletal growth patterns.[8,12,14,19]

In terms of the AP characteristics, the finding that the heritability values for SNB and facial angle were high in both the Class I and Class II groups (SNB, 0.86 and 0.89, respectively; facial angle, 0.74 and 0.80, respectively; Table 4) was similar to that of previous studies,[18,19] which reported that SNB was under a strong genetic influence.

In terms of the vertical characteristics, a greater number of cephalometric variables showed high A values for the AP characteristics than for the vertical characteristics in the Class I group (six variables: SNA, SNB, facial convexity angle, facial angle, Pog-N perpendicular, and mandibular body length to anterior cranial base vs. two variables: FH-PP and PP-MP; Table 4), which was in accordance with the findings of Sidlauskas et al.[19] However, other studies suggested that the vertical variables showed higher heritability than did the AP variables.[8,13] This difference might have originated because of the inclusion of twin samples with different ages or ethnic backgrounds.

In terms of the dental characteristics, the heritability values for the inclination of the maxillary incisors and mandibular incisors as well as the interincisal angle were higher in the Class I group than in the Class II group (U1-FH, 0.82 vs. 0.56; U1-PP, 0.73 vs. 0.59; IMPA, 0.87 vs. 0.58; interincisal angle, 0.75 vs. 0.12; Table 4). In contrast, the angle between the occlusal plane and the maxillary or mandibular incisors exhibited low-to-moderate heritability in both the Class I and Class II groups (U1-OP, 0.20 and 0.00; L1-OP, 0.21 and 0.43; Table 4). These findings indicated the need to consider the differences in the pattern of dental compensation of the maxillary and mandibular incisors between patients with Class I and Class II malocclusions.

In terms of the mandibular characteristics, the finding that mandibular body length (Go-Me) had a high A value in the Class I group (0.75; Table 4) was similar to the results of previous studies.[13,15] However, the Class II group showed a different pattern. (1) The A value of Go-Me was moderate in the Class II group (0.55; Table 4), and (2) the heritability values for effective mandibular length and ramus height were higher in the Class II group than in the Class I group (CD-Gn, 0.74 vs. 0.00; Ar-Go, 0.81 vs. 0.00; Table 4). These findings implied that patients with skeletal Class I and Class II malocclusions might have different genetic influences on the size and shape of the mandible. For example, a strong genetic influence was observed on the mandibular body length in patients with skeletal Class I malocclusion and

Table 3. The effect of genetic and environmental factors on the facial anteroposterior, facial vertical, dental, mandibular, and cranial base variables measured in the Class I and Class II groups

Cephalometric variable		Class I group		Class II group	
		r_{mz}	r_{dz}	r_{mz}	r_{dz}
Facial anteroposterior	SNA (°)	0.8734	0.2669	0.7971	0.7297
	SNB (°)	0.9093	0.1711	0.8475	0.5774
	ANB (°)	0.3208	−0.3771	0.5265	0.0237
	Facial convexity angle (NA-Pog, °)	0.6272	−0.5416	0.5662	0.5351
	Facial angle (FH-NPog, °)	0.8499	0.5911	0.8230	0.1797
	A-N perpendicular (mm)	0.7177	0.3745	0.6063	−0.2908
	Pog-N perpendicular (mm)	0.7767	0.2050	0.7055	0.2208
	Mandibular body length/ anterior cranial base (Go-Me/S-N)	0.8140	0.0793	0.6307	0.9211
Facial vertical	FH-PP (°)	0.7236	−0.2690	0.5624	0.8477
	FMA (°)	0.7737	0.6259	0.8516	0.6647
	PP-MP (°)	0.7947	−0.4834	0.8705	0.5104
	Bjork sum (°)	0.8367	−0.2503	0.8772	0.7987
	Anterior facial height (AFH, N-Me, mm)	0.9343	0.8561	0.9386	0.0557
	Posterior facial height (PFH, S-Go, mm)	0.8937	0.8670	0.9459	0.5514
	N-ANS/ANS-Me	0.6224	0.4323	0.8858	0.5315
Dental	U1-FH (°)	0.8424	−0.5742	0.6243	−0.0880
	U1-PP (°)	0.7284	−0.5928	0.6274	0.0784
	U1-OP (°)	0.6576	0.2775	0.5073	0.7615
	IMPA (°)	0.8583	−0.0917	0.6892	0.2079
	L1-OP (°)	0.7144	0.6386	0.5480	−0.6280
	Interincisal angle (°)	0.7618	0.1741	0.7709	0.7106
	FH-OP (°)	0.5391	−0.2724	0.8685	0.5846
	OP-MP (°)	0.2113	0.5529	0.6989	−0.1669
Mandible	Gonial angle (Ar-Go-Gn, °)	0.7241	0.6508	0.5764	0.3033
	Upper gonial angle (Ar-Go-N, °)	0.4816	0.6336	0.2193	−0.1697
	CD-Gn (mm)	0.2279	0.6605	0.8234	0.3373
	Go-Me (mm)	0.8756	−0.5329	0.7662	0.8101
	Ar-Go (mm)	0.8455	0.8664	0.9072	0.5218
Cranial base	Saddle angle (N-S-Ar, °)	0.7366	0.0286	0.7372	0.7375
	Cranial base angle (N-S-Ba, °)	0.9093	−0.1470	0.7255	0.9811
	S-N (mm)	0.9184	0.9953	0.8933	0.4504
	S-Ar (mm)	0.9351	0.7824	0.8194	0.6911
	Ar-N (mm)	0.9241	0.7717	0.9635	0.5517

r_{dz}, Pearson's correlation coefficients of the dizygotic twin (DZ) group; r_{mz}, Pearson's correlation coefficients of the monozygotic twin (MZ) group.
See Figure 1 and 2 for definition of each landmark or measurement.

on the overall shape of the mandible and the ramus height in patients with skeletal Class II malocclusion.

In terms of the cranial base characteristics, the saddle angle showed a moderate A value and a low C value in the Class I group (0.68 and 0.00, respectively; Table 4) and a low A value and a moderate C value in the Class II

Table 4. Genetic effects (A), common environmental effects (C), and specific environmental effects (E) of the facial anteroposterior, facial vertical, dental, mandibular, and cranial base structures in the Class I and Class II groups

Variable		Class I group			Class II group		
		A	C	E	A	C	E
Facial anteroposterior	SNA (°)	0.7982*	0.0000	0.2018	0.4498	0.3955	0.1547
	SNB (°)	0.8590*	0.0000	0.1410	0.8931*	0.0000	0.1069
	ANB (°)	0.1321	0.0000	0.8679	0.4257	0.0000	0.5743
	Facial convexity angle (NA-Pog, °)	0.7367*	0.0000	0.2633	0.1765	0.3454	0.4781
	Facial angle (FH-NPog, °)	0.7360*	0.1087	0.1553	0.8042*	0.0000	0.1958
	A-N perpendicular (mm)	0.6615	0.0000	0.3385	0.4757	0.0000	0.5243
	Pog-N perpendicular (mm)	0.8358*	0.0000	0.1642	0.6434	0.0000	0.3566
	Mandibular body length/ anterior cranial base (Go-Me/S-N)	0.7035*	0.0000	0.2965	0.3501	0.3118	0.3380
Facial vertical	FH-PP (°)	0.7401*	0.0000	0.2599	0.0642	0.6035	0.3323
	FMA (°)	0.1165	0.6352	0.2483	0.6195	0.2124	0.1681
	PP-MP (°)	0.7404*	0.0000	0.2596	0.8364*	0.0000	0.1636
	Bjork sum (°)	0.3087	0.4786	0.2128	0.4854	0.3729	0.1417
	Anterior facial height (AFH, N-Me, mm)	0.0846	0.8404	0.0751	0.9324*	0.0000	0.0676
	Posterior facial height (PFH, S-Go, mm)	0.0000	0.8540	0.1460	0.9163*	0.0000	0.0837
	N-ANS/ANS-Me	0.4987	0.0768	0.4245	0.1010	0.6641	0.2350
Dental	U1-FH (°)	0.8151*	0.0000	0.1849	0.5566	0.0000	0.4434
	U1-PP (°)	0.7293*	0.0000	0.2707	0.5933	0.0000	0.4067
	U1-OP (°)	0.1983	0.3129	0.4889	0.0000	0.5099	0.4901
	IMPA (°)	0.8714*	0.0000	0.1286	0.5797	0.0000	0.4203
	L1-OP (°)	0.2119	0.4638	0.3243	0.4283	0.0000	0.5717
	Interincisal angle (°)	0.7493*	0.0000	0.2507	0.1168	0.6150	0.2682
	FH-OP (°)	0.5430	0.0000	0.4570	0.2883	0.5207	0.1909
	OP-MP (°)	0.0000	0.2587	0.7413	0.6122	0.0000	0.3878
Mandible	Gonial angle (Ar-Go-Gn, °)	0.3883	0.3699	0.2418	0.4909	0.0000	0.5091
	Upper gonial angle (Ar-Go-N, °)	0.0000	0.5191	0.4809	0.0000	0.0000	1.0000
	CD-Gn (mm)	0.0000	0.3401	0.6599	0.7422*	0.0000	0.2578
	Go-Me (mm)	0.7543*	0.0000	0.2457	0.5460	0.1999	0.2541
	Ar-Go (mm)	0.0000	0.7915	0.2085	0.8067*	0.0601	0.1332
Cranial base	Saddle angle (N-S-Ar, °)	0.6756	0.0000	0.3244	0.0000	0.6761	0.3239
	Cranial base angle (N-S-Ba, °)	0.8640*	0.0000	0.1360	0.2826	0.4946	0.2228
	S-N (mm)	0.0436	0.8224	0.1340	0.8392*	0.0552	0.1056
	S-Ar (mm)	0.3224	0.6076	0.0700	0.8025*	0.0000	0.1975
	Ar-N (mm)	0.1854	0.6938	0.1208	0.9037*	0.0564	0.0398

*These numbers indicate high heritability (i.e., A values above 0.7).
See Figure 1 and 2 for definition of each landmark or measurement.

group (0.00 and 0.68, respectively; Table 4), which were similar to the results of previous studies.[14,17] Since those studies included younger twins who had not completed growth,[14,17] the heritability estimates of the saddle angle might be low-to-moderate in both younger and adult twins with Class I and Class II malocclusions.

In the present study, PCA extracted eight and seven components with 88.3% and 91.0% cumulative expla-

Table 5. Principal component analysis (PCA) after varimax rotation in the Class I group with 88.31% explanation

Class I group	PCA1	PCA2	PCA3	PCA4	PCA5	PCA6	PCA7	PCA8
FMA (°)	0.939	−0.146	−0.025	0.042	0.037	0.225	−0.075	0.024
Bjork sum (°)	0.848	−0.100	−0.201	0.415	−0.003	0.029	0.022	0.082
PP-MP (°)*	0.816	−0.259	−0.178	0.034	−0.024	0.117	−0.027	−0.413
OP-MP (°)	0.788	0.254	−0.139	−0.096	0.003	0.302	−0.105	0.075
U1-PP (°)*	0.031	0.930	0.138	0.085	−0.140	−0.049	−0.083	0.152
U1-FH (°)*	−0.083	0.927	0.040	0.084	−0.196	−0.137	−0.053	−0.150
FH-OP (°)	0.044	−0.846	−0.050	−0.083	−0.005	−0.093	0.021	−0.163
U1-OP (°)	0.088	−0.712	−0.028	−0.035	0.282	−0.016	0.038	0.342
Facial angle (FH-NPog, °)*	−0.481	0.550	0.000	−0.258	0.454	−0.003	0.360	−0.099
Anterior facial height (AFH, N-Me, mm)	0.079	0.104	0.946	0.136	0.045	−0.034	−0.037	0.065
Ar-N (mm)	−0.181	0.106	0.832	0.109	−0.373	0.146	−0.074	0.028
S-Ar (mm)	−0.092	−0.079	0.809	−0.273	−0.035	−0.267	0.108	0.117
Posterior facial height (PFH, S-Go, mm)	−0.560	0.041	0.785	−0.123	0.043	−0.015	−0.030	−0.006
Ar-Go (mm)	−0.604	0.107	0.657	0.087	0.087	0.275	−0.071	−0.073
CD-Gn (mm)	0.095	0.172	0.597	0.108	0.053	0.495	0.265	0.105
Cranial base angle (N-S-Ba, °)*	−0.058	0.095	0.078	0.904	−0.071	0.206	0.033	−0.065
Saddle angle (N-S-Ar, °)	0.009	0.187	0.327	0.846	−0.093	0.167	0.050	0.128
SNB (°)*	−0.286	0.045	0.365	−0.781	0.147	−0.013	0.251	−0.176
SNA (°)	−0.241	−0.119	0.289	−0.722	0.039	−0.021	0.512	−0.139
IMPA (°)*	−0.331	0.059	0.008	0.107	−0.883	−0.048	0.097	−0.016
L1-OP (°)	−0.240	−0.259	−0.029	−0.129	0.856	−0.179	−0.097	0.038
Interincisal angle (°)*	−0.176	−0.587	−0.020	−0.148	0.730	−0.021	−0.030	0.130
S-N (mm)	−0.211	0.139	0.424	−0.103	−0.525	0.386	−0.267	−0.133
Upper gonial angle (Ar-Go-N, °)	0.329	0.023	0.141	0.123	−0.109	0.825	0.033	−0.100
Mandibular body length/anterior cranial base (Go-Me/S-N)*	−0.071	0.350	0.181	−0.305	0.330	−0.730	0.223	0.026
Gonial angle (Ar-Go-Gn, °)	0.624	0.001	0.140	0.139	0.095	0.717	0.032	−0.074
Go-Me (mm)	−0.245	0.496	0.372	−0.312	0.115	−0.557	0.116	−0.026
Pog-N perpendicular (mm)*	0.245	−0.255	0.209	0.340	−0.225	−0.385	−0.205	0.179
A-N perpendicular (mm)	−0.269	0.151	0.087	−0.330	0.057	−0.007	0.841	−0.159
ANB (°)	0.111	−0.453	−0.203	0.134	−0.283	−0.025	0.741	0.103
Facial convexity angle (NA-Pog, °)*	−0.293	0.518	−0.095	0.077	0.512	0.006	−0.554	0.035
FH-PP (°)*	0.123	−0.017	0.243	0.011	0.102	0.055	−0.183	0.863
N-ANS/ANS-Me	−0.169	−0.037	−0.076	0.186	0.009	−0.169	0.073	0.790

*These cephalometric variables indicate high heritability (i.e., A values above 0.7).
See Figure 1 and 2 for definition of each landmark or measurement.

nation in the Class I and Class II groups, respectively (Tables 5 and 6). However, previous twin studies reported lower explanation powers than did this study (range: 81.0–83.0%; number of components: 5–9).[8,16,19] The differences between the present study and previous studies might be due to the variations in study designs and statistical criteria used for determining the principal components.[21,22]

In summary, the results of this study demonstrated several differences in the genetic heritability of skeleto-dental characteristics between subjects with Class I and Class II malocclusions. Subjects with Class I malocclu-

Table 6. Principal component analysis (PCA) after varimax rotation in the Class II group with 90.99% explanation

Class II group	PCA1	PCA2	PCA3	PCA4	PCA5	PCA6	PCA7
Bjork sum (°)	0.977	0.006	−0.069	−0.036	0.036	0.096	0.162
Anterior facial height (AFH, N-Me, mm)*	−0.968	−0.116	0.114	0.100	−0.071	−0.087	−0.078
Gonial angle (Ar-Go-Gn, °)	0.961	−0.112	0.012	0.015	0.115	0.102	0.076
S-N (mm)*	−0.950	−0.116	−0.029	0.041	−0.144	−0.004	−0.021
Saddle angle (N-S-Ar, °)	0.937	0.067	−0.122	−0.096	−0.058	0.023	0.191
Upper gonial angle (Ar-Go-N, °)	−0.933	−0.102	0.082	0.045	−0.048	−0.078	−0.238
FH-PP (°)	−0.926	−0.078	0.105	0.088	−0.039	0.133	−0.136
S-Ar (mm)*	−0.921	0.030	−0.149	0.084	0.138	−0.097	0.155
Cranial base angle (N-S-Ba, °)	0.898	0.062	−0.153	−0.115	−0.060	0.076	0.198
Ar-Go (mm)*	−0.895	0.125	0.139	0.000	0.129	−0.062	0.154
CD-Gn (mm)*	−0.835	0.035	−0.012	−0.055	0.024	−0.077	0.454
Posterior facial height (PFH, S-Go, mm)*	−0.831	0.172	−0.004	0.025	0.249	−0.052	0.347
IMPA (°)	0.828	0.203	−0.074	0.070	−0.006	−0.245	0.203
Ar-N (mm)*	0.755	0.073	−0.301	−0.095	0.016	0.139	0.489
FMA (°)	0.729	−0.580	0.224	0.205	0.023	0.042	−0.032
Pog-N perpendicular (mm)	−0.032	−0.913	−0.036	0.221	−0.096	0.045	−0.002
Facial angle (FH-NPog, °)*	−0.009	0.866	0.042	−0.200	0.344	0.002	0.092
PP-MP (°)*	−0.090	−0.706	0.329	0.262	−0.097	−0.326	−0.268
A-N perpendicular (mm)	−0.041	0.671	0.130	0.532	0.396	0.008	0.042
U1-PP (°)	−0.068	0.046	0.930	−0.029	0.231	−0.076	0.121
U1-FH (°)	0.194	0.076	0.871	−0.075	0.202	−0.317	0.118
U1-OP (°)	0.526	0.227	−0.765	−0.192	−0.010	−0.131	0.088
Interincisal angle (°)	0.509	0.209	−0.608	−0.231	0.034	0.467	0.116
ANB (°)*	−0.064	−0.162	−0.023	0.957	0.055	−0.067	−0.003
Facial convexity angle (NA-Pog, °)	0.050	0.255	−0.061	−0.944	0.011	−0.034	0.096
SNA (°)	0.009	0.257	0.156	0.253	0.892	−0.032	0.142
SNB (°)	0.036	0.328	0.168	−0.138	0.885	−0.005	0.146
N-ANS/ANS-Me	0.348	0.378	−0.361	−0.032	−0.551	0.404	0.086
L1-OP (°)	0.379	0.046	−0.205	−0.210	0.100	0.784	0.034
FH-OP (°)	−0.359	−0.379	−0.052	0.330	−0.187	0.658	−0.150
OP-MP (°)	−0.034	−0.492	0.164	−0.062	0.188	−0.621	0.135
CD-Gn (mm)	0.621	−0.068	0.210	0.042	0.108	0.055	0.628
Mandibular body length/anterior cranial base (Go-Me/S-N)	0.104	0.261	0.135	−0.127	0.310	−0.178	0.594

*These cephalometric variables indicate high heritability (i.e., A values above 0.7).
See Figure 1 and 2 for definition of each landmark or measurement.

sion exhibited strong genetic influences on the facial AP characteristics, mandibular body length, inclination of the maxillary and mandibular incisors, and cranial base angle, whereas those with Class II malocclusion revealed strong genetic influences on the vertical facial height, ramus height, effective mandibular length, and cranial base length (Table 4). Therefore, the response to orthodontic treatment and/or growth modification treatment in patients with skeletal Class II malocclusion might be different from that of patients with of Class I malocclusion.

Although this study reported the differences in the

heritability of skeletodental characteristics between subjects with skeletal Class I and Class II malocclusions, it has several limitations and provides some considerations for future studies. (1) It is necessary to perform a prospective longitudinal study for investigating the growth patterns in twins from childhood, to young adulthood, to middle-age; (2) The number of twins included should be increased to investigate the diverse combinations between the AP (Class I, II, and III relationships) and vertical aspects (normo-, hyper-, and hypo-divergent patterns), (3) Performing more sophisticated statistical analyses and using machine learning for growth prediction would also be helpful, and (4) three-dimensional analysis using low-density cone beam computed tomography images would be necessary to explore the characteristics of transverse growth patterns.

CONCLUSION

• Twin pairs with Class I malocclusion exhibited strong genetic influences on the facial AP characteristics, mandibular body length, inclination of the maxillary and mandibular incisors, and cranial base angle, whereas those with Class II malocclusion showed strong genetic influences on vertical facial height, ramus height, effective mandibular length, and cranial base length.

• The results of this study demonstrated the differences in the heritability of skeletodental characteristics between twin pairs with skeletal Class I and Class II malocclusions, thereby providing valuable information for predicting growth and planning orthodontic and/or orthopedic treatments for patients with Class I and Class II malocclusions.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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