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Observational study investigating the relationship between maxillomandibular characteristics and temporomandibular disc conditions in female patients with a skeletal class III pattern

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Abstract

OBJECTIVES: The objective of this study was to analyze the relationship between maxillomandibular characteristics and the severity of temporomandibular disc displacement in female patients with a skeletal class III (SKIII) pattern.

METHODS: Fifty-seven samples were included in the study. The evaluation of articular disc conditions was conducted using magnetic resonance imaging, while 25 cephalometric variables from lateral and postero-anterior (P-A) cephalograms were measured to determine their maxillomandibular characteristics. The samples were categorized into three groups based on the articular disc conditions: (1) normal disc position (NDP), (2) disc displacement with reduction (DDwR), and (3) disc displacement without reduction (DDwoR). The relationship between the maxillomandibular characteristics and disc conditions was examined through both basic statistical analysis and multivariate analysis using principal component analysis (PCA).

RESULTS: The Kruskal–Wallis and Dunn–Bonferroni tests revealed a significant difference between the groups in terms of the deviation of mandibular characteristics observed on the P-A cephalogram. The DDwoR group exhibited significantly larger menton deviation, ramal height asymmetry index, and total mandibular length asymmetry index compared to the NDP and DDwR groups. Moreover, the PCA successfully extracted all cephalometric variables into eight principal components. Among them, only the principal component related to mandibular asymmetry was able to differentiate the SKIII samples with DDwoR from the other groups.

CONCLUSIONS: The findings of this study highlight a significant relationship between mandibular asymmetry and the severity of disc displacement, particularly DDwoR, in female patients with a SKIII pattern.

Keywords:

Articular disc displacement, facial asymmetry, skeletal class III, temporomandibular joint disorder

Background

Dentofacial deformity (DFD) and temporomandibular joint disorder (TMD) are critical problems in clinical orthodontics and are known to significantly affect patients' quality of life.[1,2] DFD typically develops during early adolescence, although it may only become apparent

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during or after the maximum pubertal growth period. Similarly, TMD tends to develop during the adolescent growth period or later. Patients with DFD have a higher prevalence of TMD compared to the control population.[3] While TMD can develop through various biomedical processes, the maxillomandibular morphological deviation in the sagittal, vertical, and transverse facial planes is considered a significant factor in the development of TMD. Skeletal class III (SKIII) malocclusion is particularly prevalent in the Asian population,[4] and the maxillomandibular characteristics of SKIII patients and their relationship with articular disc displacement have yet to be clarified.

Articular disc displacement in the temporomandibular joint (TMJ) serves as a significant indicator of TMD.[5,6] Previous studies have demonstrated a strong correlation between articular disc displacement and the severity of symptoms in TMD patients.[7-9] Magnetic resonance imaging (MRI) enables accurate and reproducible determination of articular disc displacement.[10-12] MRI assessments are conducted in both the closed-mouth and opened-mouth positions to evaluate the status of the articular disc.[7,13] In the closed-mouth position, articular disc displacement is diagnosed when the articular disc is not superiorly located at the 12 o'clock position of the mandibular condyle. The severity of disc displacement in the opened-mouth position is assessed by observing the degree of reduction of disc displacement into the superior position of the condyle. Disc displacement with or without reduction is potentially associated with the severity of TMD, including limited mouth opening, pain, and/or degenerative changes of the mandibular condyle.[14-16]

Sagittally retrognathic and vertically hyperdivergent mandibles are skeletal characteristics that may have a significant association with the severity of articular disc displacement, although there is currently no clear evidence supporting this claim.[17] Among the various maxillomandibular classifications in the sagittal facial planes, SKIII malocclusion may have the weakest association with articular disc displacement.[18] It is likely that a transversely deviated mandible is linked to articular disc displacement, as patients with skeletal facial asymmetry commonly exhibit clinical TMD symptoms.[19] Therefore, the objectives of the present study were to analyze the relationship between the antero-posterior and transverse maxillomandibular characteristics in SKIII patients, patterns of disc conditions in the TMJ, and their correlation with the severity of TMD. Our hypothesis was that more severe articular disc displacement in the TMJ would likely be associated with a greater deviation in maxillomandibular characteristics among SKIII patients. Basic statistical and multivariate analyses were employed to identify the cephalometric parameters directly related to TMD severity.

Methods

Samples

Female patients who sought orthodontic treatment at our institution between 2009 and 2018 were included in the study. All SKIII patients exhibited an angle formed by point A, nasion, and point B (ANB)<2.3° and Wits appraisal <−4 mm in lateral cephalometric image, based on the normal values for the female population in Japan.[20,21] The sample size was calculated considering the incidence of articular disc displacement in 84% of Japanese females with SKIII pattern,[22] at a 95% confidence interval and a precision level of 10%. A minimum of 52 samples was required. Exclusion criteria were as follows: (1) congenital defects, (2) history of orthodontic treatment, (3) history of TMJ-related trauma and surgery, (4) history of tooth extraction, excluding third molars, (5) unavailability of pre-treatment cephalograms or TMJ-MRI scans, and (6) poor-quality radiographs and MRI scans. In this study, 57 SKIII samples were included. The average age of the patients at the initial visit was 22.48 ± 7.14 years (range, 14.08–47.42). All patient images were assigned numerical codes and evaluated by an investigator who was blind to the patients' identification and clinical condition.

MRI scans and analyses

The articular disc condition of the patients s was assessed on the sagittal-oblique images of the TMJ obtained using a 1.5-T MRI scanner (Symphony, Siemens, Erlangen, Germany or Gyroscan Intera, Philips, Eindhoven, the Netherlands) in both closed-mouth and opened-mouth positions. The interpretation of each MRI scan was conducted by a radiologist who was not aware of the patient's history. The articular disc conditions in each TMJ were depicted in Figure 1 and described in Table 1.

The samples were divided into three groups based on the severity of the disc condition: (1) normal disc position (NDP; $n = 24$) on both sides of the TMJ; (2) disc displacement with reduction (DDwR; $n = 23$), consisting of either bilateral DDwR or unilateral DDwR with NDP on the other joint; and (3) disc displacement without reduction (DDwoR; $n = 10$), consisting of DDwoR on at least one joint.

Cephalometric images and analyses

The postero-anterior (P-A) and lateral cephalometric images were traced on a Cintiq digitizer interface version 21UX (Wacom, Saitama, Japan) using CorelDraw Essentials software version X6 (Corel, Ottawa, Canada). The anatomical landmarks and reference planes used in this study are indicated in Figure 2. On a P-A cephalogram, the line between both sides of the lateral orbitale was defined as the horizontal reference plane, and the line perpendicular

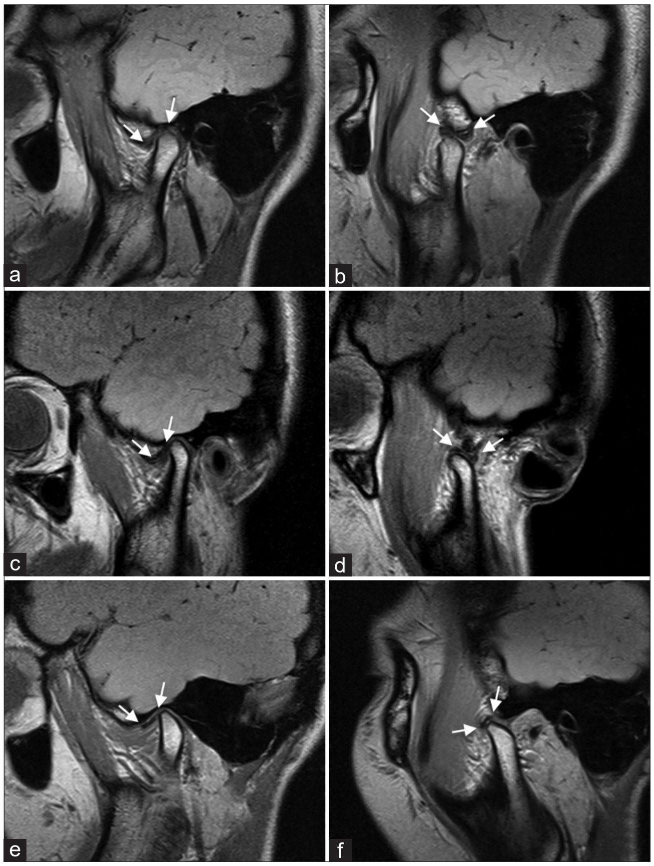

Figure 1: Analysis of MRI scans. The representative appearance of the articular disc condition is shown. The left column is the MRI scan in sagittal-oblique sections in the closed-mouth position; the right column is the MRI scan in sagittal-oblique sections in the opened-mouth position. (a and b) Normal disc position (NDP). (c and d) Disc displacement with reduction (DDwR). (e and f) Disc displacement without reduction (DDwoR)

to the horizontal reference plane passing through the tip of the crista galli was defined as the mid-facial plane. All 25 cephalometric variables were measured using Winceph software, version 9.0 (Rise, Sendai, Japan), as described in Tables 2 and 3 for the respective P-A and lateral cephalometric measurements. The bilateral variables on the P-A cephalograms were calculated into an asymmetry index using the following formula[23-25]:

$$\frac{\text{Difference between the right and left side values}}{\text{Average of the right and left side values}} \times 100$$

Statistical analysis

All cephalometric images were traced and measured twice after a 7-day interval by the same observer to minimize errors. Subsequently, an intraclass correlation coefficient analysis was conducted using statistical software, which exhibited a value >0.95, indicating excellent intraobserver reliability.

The differences in maxillomandibular characteristics among the three groups of disc conditions (NDP, DDwR, and DDwoR) were analyzed using the Kruskal–Wallis and Dunn–Bonferroni tests at a significance level of 0.05.

Table 1: Definition of articular disc conditions

Articular disc condition	Definitions
Normal disc position (NDP)	Posterior band of the disc is placed at the 12 o'clock position of the condylar head for sagittal-oblique sections in the closed-mouth position
Disc displacement with reduction (DDwR)	Posterior band is placed anteriorly to the 12 o'clock position of the condylar head for sagittal-oblique section in the closed-mouth position. The disc is superiorly reduced on the condylar head in the opened-mouth position
Disc displacement without reduction (DDwoR)	Posterior band is placed anteriorly to the 12 o'clock position of the condylar head for sagittal-oblique section in the closed-mouth position. Disc does not reduce to the normal position on sagittal-oblique sections in the opened-mouth position

A total of 25 maxillomandibular variables measured on the P-A and lateral cephalograms were used to extract the principal components of the maxillomandibular characteristics for principal component analysis (PCA). The distribution of articular disc conditions in the SKIII samples was based on the first three principal components.

All statistical analyses were performed using IBP SPSS Statistics, version 25.0 (IBM Corp., Armonk, NY, USA).

Results

Of the maxillomandibular characteristics analyzed on the P-A cephalograms [Table 4], four variables related to mandibular characteristics were found to differ significantly among the study groups. No significant differences were observed in the maxillary parameters. As shown in Figure 3, individuals in the DDwoR group exhibited significantly larger menton deviation, FMdP cant, Cd-Ag asymmetry index, and Cd-Me asymmetry index compared to those in the bilateral NDP group ($P < 0.01$). Furthermore, participants in the DDwoR group displayed significantly larger menton deviation, Cd-Ag asymmetry index, and Cd-Me asymmetry index compared to those in the DDwR group ($P < 0.05$).

Regarding the maxillomandibular characteristics analyzed on the lateral cephalograms, no significant differences were observed among the groups [Table 5]. This implies that there were no statistically significant difference in angular or linear measurements related to antero-posterior jaw position and relationship, including facial convexity, SNA, SNB, ANB, and Wit's appraisal, among the groups. Furthermore, there were no differences between the groups in the lateral cephalometric parameters indicating mandibular size or parameters related to vertical facial balance, such as the

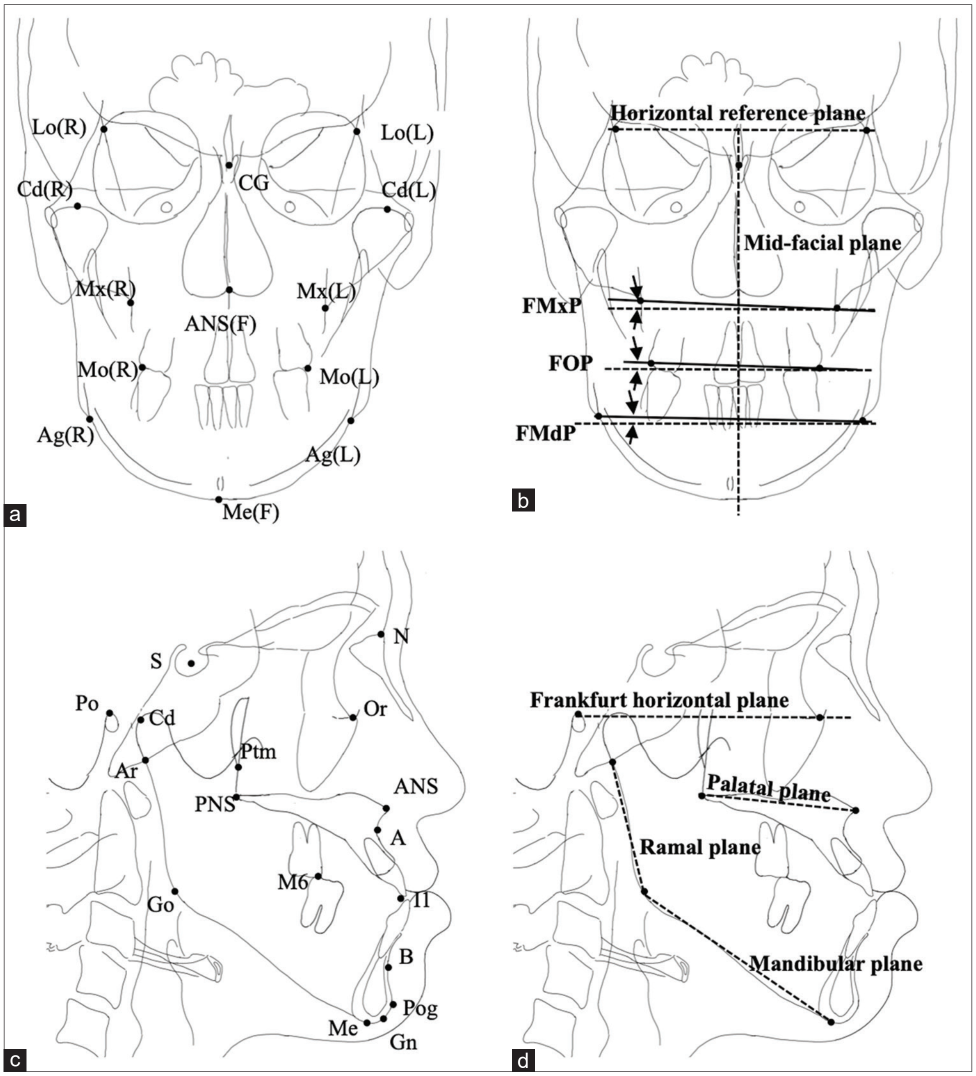

Figure 2: Reference points and planes are shown for P-A (a and b) and lateral (c and d) cephalometric analyses. (a) Ag, antegonial notch; ANS, anterior nasal spine; Cd, condylion; CG, crista galli; Lo, lateral orbitale; Me, menton; Mo, buccal tip of upper first molar; Mx, deepest point on the curve of the molar process of maxilla. (b) Reference planes and variable planes in P-A cephalograms are shown. FMdP, frontal mandibular plane; FMxP, frontal maxillary plane; FOP, frontal occlusal plane. (c) A, point A; ANS, anterior nasal spine; Ar, articulare; B, point B; Cd, condylion; Gn, gnathion; Go, gonion; I1, point between the tips of the upper and lower incisors; Me, menton; M6, point between cuspal tips of the upper and lower first molars; N, nasion; Or, orbitale; PNS, posterior nasal spine; Po, porion; Pog, pogonion; Ptm, pterygomaxillary fissure; S, sella. (d) Reference planes and variable planes in lateral cephalograms are shown

Frankfort-mandibular plane angle, palatal plane angle, N-ANS, and N-Me.

The rotated component matrix for the PCA is presented in Table 6. The 25 cephalometric variables were categorized into eight principal components with an eigenvalue higher than 1.00. The first principal component primarily represented mandible asymmetry (menton deviation, FMdP cant, and mandibular asymmetry indices). The second principal component included variables related to the antero-posterior maxillomandibular relationship (ANB angle, facial convexity, and Wit's appraisal). The third and fourth principal components were associated with the vertical mandibular orientation (mandibular plane angle, gonial angle, and ramal inclination) and mandibular size (total mandibular length, ramus height, lower face height, and mandibular body length), respectively. The remaining principal components mostly represented variables related to maxillary characteristics.

A scatterplot depicting the samples with NDP, DDwR, and DDwoR on each pair of the first three principal components is presented in Figure 4. Additionally, a scatterplot illustrating the articular disc conditions on each pair of all eight principal components can be found in the Supplementary Figure. These figures suggest that only the first principal component is capable of distinguishing temporomandibular disc conditions in female SKIII patients.

Discussion

Maxillofacial morphology, particularly the deviated characteristics of the mandible, is considered one of the

Table 2: Definition of P-A cephalometric measurements

P-A cephalometric variables	Definitions
Frontal maxillary plane cant: (FMxP cant) (°)	Angle between the line connecting the Mx (R) and Mx (L) points, and a horizontal reference plane
Frontal occlusal plane cant: (FOP cant) (°)	Angle between the line connecting the Mo (R) and Mo (L) points, and a horizontal reference plane.
Frontal mandibular plane cant: (FMdP cant) (°)	Angle between the line connecting the Ag (R) and Ag (L) points, and a horizontal reference plane.
ANS deviation (mm)	Distance of ANS (F) from the mid-facial plane
Menton deviation (mm)	Distance of Me (F) from the mid-facial plane
Asymmetry index of Mx width (Mx width asym index) (%)	Asymmetry index formulated from left and right maxillary width (Mx point to mid-facial plane)
Asymmetry index of Mx height (Mx height asym index) (%)	Asymmetry index formulated from left and right maxillary height (Mx point to horizontal reference plane)
Asymmetry index of ramus (Cd-Ag asym index) (%)	Asymmetry index formulated from left and right ramus height (Cd point to Ag point)
Asymmetry index of mandibular body (Ag-Me asym index) (%)	Asymmetry index formulated from left and right mandibular body length (Ag point to Me point)
Asymmetry index of total mandible length (Cd-Me asym index) (%)	Asymmetry index formulated from left and right total mandibular length (Cd point to Me point)

Table 3: Definition of lateral cephalometric measurements

Lateral cephalometric variables	Definitions
SNA angle (°)	Angle between S-N and N-A
SNB angle (°)	Angle between S-N and N-B
ANB (°)	SNA-SNB
Facial convexity (°)	Angle between N-A and A-Pog
Palatal plane angle (°)	Angle between FH and palatal plane (anterior nasal spine (ANS) point to posterior nasal spine (PNS) point)
FMA (°)	Angle between FH and mandibular plane (Go-Me)
Ramal inclination (RI) (°)	Angle between FH and ramal plane (Ar-Go)
Gonial angle (GA) (°)	Angle between mandibular and ramal planes
N-ANS length (mm)	Distance from ANS point to N point
N-Me length (mm)	Distance from Me point to N point
Wit's appraisal (Wit's) (mm)	Distance between perpendicular lines dropped from point A and B onto the occlusal plane (line between I1-M6)
Palatal length (mm)	Distance between perpendicular lines dropped from point A and Ptm onto the palatal plane (line between ANS-PNS)
Ramus height (Cd-Go) (mm)	Distance from Cd point to Go point
Mandibular body length (Go-Pog) (mm)	Distance from Go point to Pog point
Total mandibular length (Cd-Gn) (mm)	Distance from Cd point to Gn point

etiologies associated with TMD. A significant relationship between retrognathic, hyperdivergent, and asymmetric mandibles, and the severity of articular disc displacement has been found.[17,19] Among the antero-posterior jaw relationships (SKI, SKII, and SKIII), the relationship between SKIII pattern and articular disc displacement is the smallest.[18] However, in our study, we found significant relationships between certain maxillomandibular characteristics in patients with the SKIII pattern and articular disc conditions. According to the P-A cephalometic analysis, SKIII samples with DDwoR exhibited greater mandibular asymmetry compared to those with DDwR and NDP. Furthermore, the cephalometric characteristics of the DDwR group were similar to those in the NDP group, showing no significant mandibular asymmetry. This finding suggests that asymmetric mandibular characteristics in SKIII patients may be one of the causes contributing to the severity of articular disc conditions. Moreover, among our three study groups, the group with DDwoR had the highest average values for ANB, facial convexity, Wit's appraisal, Frankfort-mandibular plane angle, gonial angle, and ramal inclination, although the differences were not determined to be statistically significant. It should also be acknowledged that despite recruiting patients with a severe SKIII pattern for our study, the magnitude of sagittal discrepancy in the jaw may not have been large enough to observe a significant difference among the groups.

In the present study, we also employed PCA to assess whether any principal components of the maxillomandibular characteristics in SKIII patients could be served as indicators for articular disc conditions. The analysis revealed that the first principal component, associated with mandibular asymmetry, effectively differentiated individuals in the SKIII group with DDwoR from those in the other groups. This finding was consistent with the outcomes of the basic statistical analysis. Our results strongly indicate that SKIII patients are likely to have a more severe articular disc condition when they demonstrate mandibular asymmetry. This study suggests that mandibular asymmetry in SKIII patients is significantly related to severe TMD, especially DDwoR.

However, the cause-and-effect relationship between TMD severity and maxillomandibular characteristics in patients with the SKIII pattern remains inconclusive in this study. Further longitudinal study by collecting SKIII samples during the growth period, or alternatively, investigating TMD condition after orthodontic-orthognathic treatment is suggested to better understand this relationship.

Conclusions

The relationship between the antero-posterior and transverse maxillomandibular characteristics of SKIII

Table 4: Maxillomandibular characteristics on P-A cephalograms among the groups of articular disc conditions

Cephalometric variables	NDP (*n*=24)	DDwR (*n*=23)	DDwoR (*n*=10)	*P*
Variables on P-A cephalogram				
ANS deviation (mm)	0.65±0.57	0.72±0.72	1.17±0.54	NS
Menton deviation (mm)	2.40±2.27	4.03±3.17	8.93±4.02	***,†
FMxP cant (°)	1.15±1.16	1.55±1.19	1.59±1.85	NS
FOP cant (°)	1.26±0.97	1.19±0.72	2.20±1.64	NS
FMdP cant (°)	0.83±0.82	1.32±1.09	2.77±1.65	**
Cd-Ag asym index (%)	3.32±2.50	3.17±2.96	7.95±5.11	**,†
Ag-Me asym index (%)	5.42±4.45	6.49±5.02	11.77±10.30	NS
Cd-Me asym index (%)	2.88±2.76	2.92±3.05	6.40±3.57	**,†
Mx width asym index (%)	5.17±4.04	4.93±3.49	6.24±3.41	NS
Mx height asym index (%)	2.25±2.25	3.08±2.25	3.05±3.51	NS

NS, not significant. DDwoR significantly differs from NDP: ***P*<0.01, ****P*<0.001. DDwoR significantly differs from DDwR: †*P*<0.05

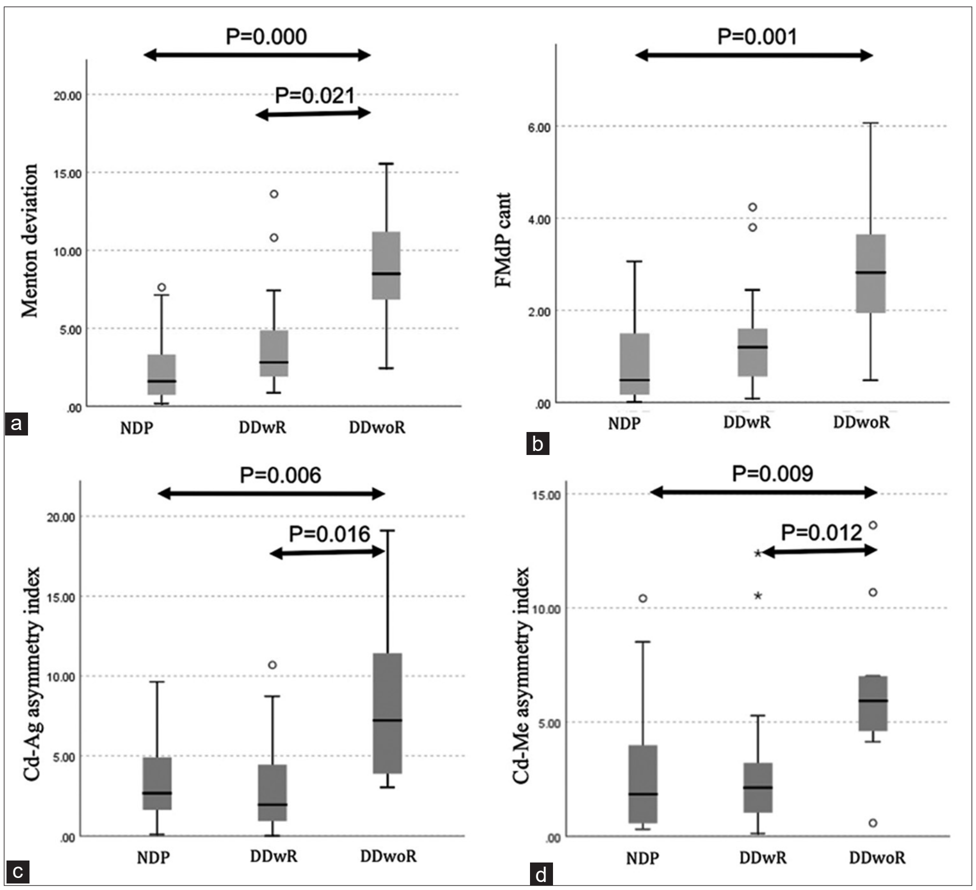

Figure 3: Box and whisker plots indicate maxillomandibular characteristics, which differ significantly among the groups according to articular disc conditions. (a) Menton deviation, (b) FMdP cant, (c) Cd-Ag asymmetry index, and (d) Cd-Me asymmetry index. NDP, normal disc position; DDwR, disc displacement with reduction; DDwoR, disc displacement without reduction

patients and the patterns of TMJ disc condition was investigated to determine their relationship with the severity of TMD. The results of a basic statistical analysis and a multivariate analysis allowed identification of the cephalometric parameters directly related to the severity of TMD. Our results indicate a strong relationship between the internal derangement of the TMJ and skeletal facial asymmetry in SKIII patients. It was also found that DDwoR, specifically, is related to maxillomandibular asymmetry.

Ethical approval

This study is applicable for human studies. The Ethics Committee of the authors' institute approved the study with the Protocol No 2020-242.

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Table 5: Maxillomandibular characteristics on lateral cephalograms among the groups of articular disc conditions

Cephalometric variables	NDP (*n*=24)	DDwR (*n*=23)	DDwoR (*n*=10)	*P*
Variables on lateral cephalogram				
SNA (°)	80.59±3.22	80.90±3.04	79.85±3.69	NS
Palatal plane angle (°)	0.14±3.59	0.34±2.61	0.30±2.72	NS
Palatal length (mm)	48.79±2.24	48.95±1.77	48.64±3.60	NS
N-ANS (mm)	57.41±3.12	57.09±3.66	57.15±1.92	NS
SNB angle (°)	82.57±3.40	82.79±3.47	80.94±5.27	NS
FMA (°)	27.22±4.50	25.75±5.90	29.89±5.79	NS
RI (°)	80.69±4.79	80.38±5.02	81.53±5.92	NS
GA (°)	126.53±6.52	125.37±8.13	128.37±8.82	NS
N-Me (mm)	131.02±7.45	130.81±6.50	132.43±7.82	NS
Cd-Go (mm)	61.08±4.53	63.50±4.48	60.95±4.66	NS
Pog-Go (mm)	82.75±3.70	82.23±3.61	81.48±3.55	NS
Cd-Gn (mm)	129.27±5.42	130.36±5.85	128.76±7.48	NS
ANB (°)	-1.99±1.79	-1.89±1.91	-1.09±3.21	NS
Facial convexity (°)	-4.41±4.88	-4.00±4.34	-2.95±7.06	NS
Wits appraisal (mm)	-11.03±2.95	-10.28±3.81	-9.11±3.94	NS

NS, not significant

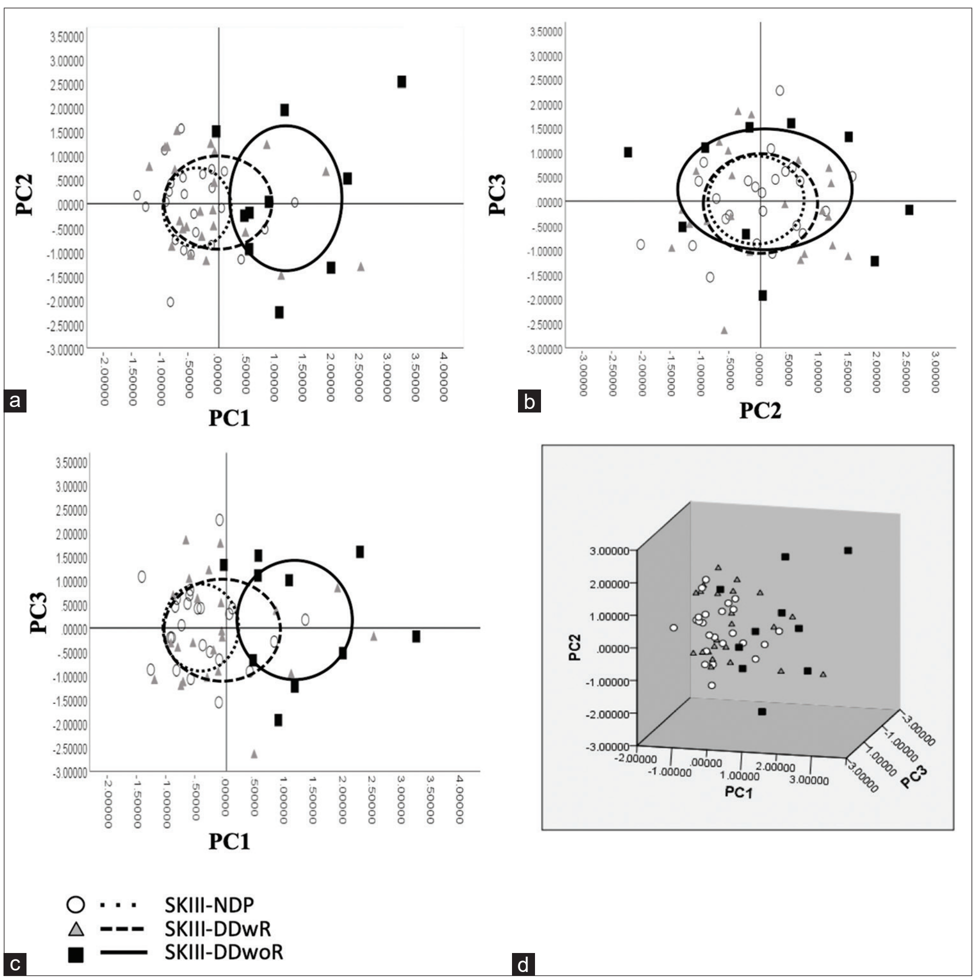


Figure 4: Scatter plots for the skeletal class III samples with different disc conditions (bilateral NDP, DDwR, and DDwoR) on the first three principal components. (a) PC1 and PC2. (b) PC2 and PC3 (c) PC1 and PC3. (d) Three-dimensional scatter plots of samples with different disc conditions among the first three principal components

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Table 6: Rotated component matrix on PCA

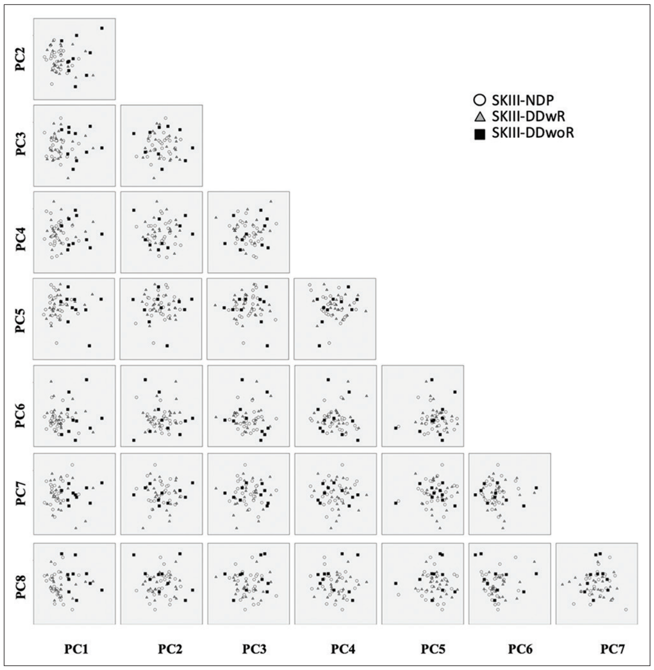
All cephalometric variables	Component 1	Component 2	Component 3	Component 4	Component 5	Component 6	Component 7	Component 8
Cd-Ag asym. index	0.863							
FMdP cant	0.842							
Menton Deviation	0.834							0.351
Cd-Me asym. index	0.774							0.332
Ag-Me asym. index	0.448		0.418		-0.312			0.357
ANB angle		0.95						
Facial convexity		0.901						
Wits		0.643	-0.454					
GA			0.981					
FMA			0.759				0.388	
RI			-0.654		-0.33		0.442	
Gn-Cd length			0.32	0.865				
Cd-Go length				0.815				
N-Me length			0.377	0.673	-0.404			
Pog-Go length		-0.33	-0.332	0.57		-0.337		
SNA					0.921			
SNB		-0.49			0.813			
palatal length				0.502	0.512			
FMxP						0.933		
Mx height asym. index						0.923		
Palatal plane angle					0.374		0.778	
N-ANS length				0.413	-0.339		0.702	
ANS deviation								0.646
Mx width asym. index						0.393		0.599
FOP		-0.321						0.525

Kaiser–Meyer–Olkin Measure of Sampling Adequacy=0.549

References

1. Lee S, McGrath C, Samman N. Quality of life in patients with dentofacial deformity: A comparison of measurement approaches. Int J Oral Maxillofac Surg 2007;36:488–92.
2. Dahlström L, Carlsson GE. Temporomandibular disorders and oral health-related quality of life. A systematic review. Acta Odontol Scand 2010;68:80–5.
3. Al-Moraissi EA, Perez D, Ellis E. Do patients with malocclusion have a higher prevalence of temporomandibular disorders than controls both before and after orthognathic surgery? A systematic review and meta-analysis. J Craniomaxillofac Surg 2017;45:1716–23.
4. Hardy DK, Cubas YP, Orellana MF. Prevalence of angle class III malocclusion: A systematic review and meta-analysis. Open J Epidemiol 2012;2:4.
5. Kircos LT, Ortendahl DA, Mark AS, Arakawa M. Magnetic resonance imaging of the TMJ disc in asymptomatic volunteers. J Oral Maxillofac Surg 1987;45:852–4.
6. Katzberg RW, Westesson PL, Tallents RH, Drake CM. Anatomic disorders of the temporomandibular joint disc in asymptomatic subjects. J Oral Maxillofac Surg 1996;54:147–53.
7. Tasaki MM, Westesson PL, Isberg AM, Ren YF, Tallents RH. Classification and prevalence of temporomandibular joint disk displacement in patients and symptom-free volunteers. Am J Orthod Dentofacial Orthop 1996;109:249–62.
8. Ribeiro RF, Tallents RH, Katzberg RW, Murphy WC, Moss ME, Magalhaes AC, *et al*. The prevalence of disc displacement in symptomatic and asymptomatic volunteers aged 6 to 25 years. J Orofac Pain 1997;11:37–47.
9. Salé H, Bryndahl F, Isberg A. Temporomandibular joints in asymptomatic and symptomatic nonpatient volunteers: A prospective 15-year follow-up clinical and MR imaging study. Radiology 2013;267:183–94.
10. Liedberg J, Panmekiate S, Petersson A, Rohlin M. Evidence-based evaluation of three imaging methods for the temporomandibular disc. Dentomaxillofac Radiol 1996;25:234–41.
11. Brooks SL, Brand JW, Gibbs SJ, Hollender L, Lurie AG, Omnell K-Å, *et al*. Imaging of the temporomandibular joint: A position paper of the American Academy of Oral and Maxillofacial Radiology. Oral Surg, Oral Med, Oral Pathol, Oral Radiol, Endod 1997;83:609–18.
12. Bag AK, Gaddikeri S, Singhal A, Hardin S, Tran BD, Medina JA, *et al*. Imaging of the temporomandibular joint: An update. World J Radiol 2014;6:567–582.
13. Ikeda R, Ikeda K. Directional characteristics of incipient temporomandibular joint disc displacements: A magnetic resonance imaging study. Am J Orthod Dentofacial Orthop 2016;149:39–45.
14. Wilkes CH. Internal derangements of the temporomandibular joint. Pathological variations. Arch Otolaryngol Head Neck Surg 1989;115:469–77.
15. Müller-Leisse C, Augthun M, Bauer W, Roth A, Günther R. Anterior disc displacement without reduction in the temporomandibular joint: MRI and associated clinical findings. J Magn Reson Imaging 1996;6:769–74.
16. Al-Baghdadi M, Durham J, Araujo-Soares V, Robalino S, Errington L, Steele J. TMJ disc displacement without reduction management: A systematic review. J Dent Res 2014;93(Suppl 7):37s-51s.
17. Manfredini D, Segù M, Arveda N, Lombardo L, Siciliani G, Alessandro R, *et al*. Temporomandibular joint disorders in patients with different facial morphology. A systematic review of the literature. J Oral Maxillofac Surg 2016;74:29–46.

18. Jung WS, Kim H, Jeon DM, Mah SJ, Ahn SJ. Magnetic resonance imaging-verified temporomandibular joint disk displacement in relation to sagittal and vertical jaw deformities. Int J Oral Maxillofac Surg 2013;42:1108–15.
19. Marques FBC, de Lima LS, Oliveira PLE, Magno MB, Ferreira DMTP, de Castro ACR, *et al*. Are temporomandibular disorders associated with facial asymmetry? A systematic review and meta-analysis. Orthod Craniofac Res 2021;24:1–16.
20. Miura F, Inoue N, Suzuki K. Cephalometric standards for Japanese according to the Steiner analysis. Am J Orthod 1965;51:288–95.
21. Miyajima K, McNamara JA Jr, Kimura T, Murata S, Iizuka T. Craniofacial structure of Japanese and European-American adults with normal occlusions and well-balanced faces. Am J Orthod Dentofacial Orthop 1996;110:431–8.
22. Ooi K, Inoue N, Matsushita K, Yamaguchi H, Mikoya T, Minowa K, *et al*. Incidence of anterior disc displacement without reduction of the temporomandibular joint in patients with dentofacial deformity. Int J Oral Maxillofac Surg 2018;47:505-10.
23. Trpkova B, Major P, Nebbe B, Prasad N. Craniofacial asymmetry and temporomandibular joint internal derangement in female adolescents: A posteroanterior cephalometric study. Angle Orthod 2000;70:81–8.
24. Masuoka N, Momoi Y, Ariji Y, Nawa H, Muramatsu A, Goto S, *et al*. Can cephalometric indices and subjective evaluation be consistent for facial asymmetry? Angle Orthod 2005;75:651–5.
25. Almăşan OC, Băciuţ M, Hedeşiu M, Bran S, Almăşan H, Băciuţ G. Posteroanterior cephalometric changes in subjects with temporomandibular joint disorders. Dentomaxillofac Radiol 2013;42:20120039.



Supplementary Figure: Scatter plots for the skeletal class III samples with different disc conditions (bilateral NDP, DDwR, and DDwoR) on each pair of all eight principal components