Effects of facial mask treatment are attributed to accelerated maxillary growth and inhibited counter-clockwise total rotation of the mandibular corpus: A structural superimposition study

Abstract

Purpose: To test the hypothesis that facial mask treatment influences maxillary sutural growth, condylar growth, and total rotation of mandibular corpus, using a structural superimposition analysis by Björk et al.

Materials and methods: Subjects consisted of 28 girls with Angle Class III malocclusion treated with facial mask (FM group). Eleven girls with pseudo-Class III malocclusion (pseudo-III group) were also examined. Pre- and posttreatment lateral cephalograms were analyzed to evaluate skeletal changes. Cephalometric structural superimposition analysis was also performed.

Results: The FM group exhibited significantly larger forward maxillary growth and negative total rotation of the mandibular corpus as compared to the pseudo-III group. In the FM group, forward maxillary skeletal growth correlated significantly with maxillary counter-clockwise rotation. Negative mandibular total rotation correlated significantly with inhibition of the forward position of the mandible.

Conclusion: Accelerated maxillary sutural growth and inhibited counter-clockwise total

rotation of mandibular corpus growth attributed to facial mask treatment may contribute to improvements in Class III malocclusion. The greater the acceleration of maxillary sutural growth due to facial mask treatment, the greater the increase in maxillary counter-clockwise rotation.

Introduction

For a growing patient diagnosed with Angle Class III malocclusion with a retrognathic maxilla, maxillary protraction appliances are used [1-6]. Many cephalometric studies have reported the effects of maxillary protraction appliances, especially facial mask [2-8].

Maxillary growth includes sutural growth, endochondral growth of the nasal septum, and periosteal growth of cortical bone. Mandibular growth includes endochondral growth of the condyle and periosteal growth of the cortical bone. Growth in length of the mandible occurs, essentially at the condyle [9]. Animal studies and a finite element study using dry skulls have suggested sutural modification as the most important determinant of sagittal growth in the naso-maxillary complex [10-12]. However, conventional cephalometric analysis cannot evaluate the effects on maxillary growth by separating sutural growth and changes in maxillary morphology derived from periosteal growth and effects on mandibular growth by separating growth at the condyle and periosteal growth.

To assess maxillofacial growth using cephalogram, external anatomical points of the maxilla and mandible (e.g. point A) may not be stable, because such points depend on local surface remodeling processes [13]. Using a structural (or regional) superimposition method based on that described by Björk and Skieller [14], Haralabakis et al [15] compared the effects of activator and cervical headgear by dividing treatment changes into maxillary growth, mandibular condylar growth, mandibular molar movement, and mandibular total rotation [14], which represents rotation of the mandibular corpus during growth. Our previous study [16] also assessed the effects of activator on mandibular growth using the structural superimposition method. No report evaluates facial mask effects using the method, even though the method may facilitate a better understanding of how maxillary sutural growth, condylar growth, and mandibular total rotation relate to jaw relationship changes during treatment using facial mask.

The purpose of the present study was to test the hypothesis that facial mask treatment influences maxillary sutural growth, condylar growth, and mandibular total rotation, using the structural superimposition analysis.

Materials and Methods

Subjects

Subjects comprised of 28 Japanese girls with Angle Class III malocclusion treated using a facial mask (FM group). Criteria for including a Class III patient in the study were: 1) overjet ≤0.0 mm; 2) Class III molar relationships; 3) retrognathic maxilla (point A to nasion perpendicular < 0.5 mm); and 4) age ≥6 years and ≤9 years at initial examination. Criteria for excluding a subject from the study were: 1) presence of congenital anomalies; 2) trauma; and 3) previous orthodontic treatment.

The extra-oral facial mask was a one-piece construction with an adjustable anterior wire and hooks to accommodate downward and forward pull of the maxilla with elastics. To avoid bite opening during repositioning of the maxilla, protraction elastics were attached near the maxillary canines with downward and forward pull directed 30° to the occlusal plane. For the intra-oral appliance, bands were fitted on the maxillary permanent first molars. In cases of early mixed dentition, bands were fitted on the primary second molars. Elastics delivering about 300 g of force per side as measured by a gauge were used. All subjects were instructed to wear the facial mask for 10-12 hours a day. Although actual wearing time for the facial mask was difficult to assess accurately, subjects who clearly demonstrated lack of compliance were excluded from the study. Mean treatment duration was 14 ± 7 months. Standardized lateral cephalograms were obtained before (T1; mean age, 8.0 ± 1.4 years) and after (T2; mean age, 9.2 ± 1.4 years) facial mask treatment.

Eleven Japanese girls with pseudo-Class III malocclusion (pseudo-III group) were also examined. Pseudo-Class III malocclusion is characterized by an anterior crossbite caused by a functional forward position of the mandible [5]. All subjects wore a lingual arch with spring [17] for improvement of the anterior crossbite by inclining the maxillary incisors labially. No patients were treated using an orthopedic appliance. All patients obtained positive overjet and overbite within 1-6 months. Standardized lateral cephalograms were obtained before treatment (T1; mean age, 8.1 ± 0.9 years) and during growth observation (T2; mean age, 9.4 ± 0.9 years). Mean age of T1 and T2 in the pseudo-III group was almost same as that in the FM group.

The ethics committee at the institution of the author’s affiliation approved all protocols in this retrospective study (approval no. 214).

Cephalometric analysis

The cephalometric measurements employed in this study are shown in Fig. 1.

Cephalometric analysis derived from the original analysis of Bjork and Skieller [18] was performed to evaluate facial mask effects by decomposing T1-T2 changes into maxillary skeletal growth and maxillary molar movement. The structural superimposition method for this analysis was applied as described previously [18] and is briefly explained below.

Superimposition of the initial and final (or interim during growth observation in pseudo-III group) tracings on the maxillary internal stable structure, anterior contours of the zygomatic processes, is shown in Fig. 2a. The dental component was represented as the distance between measurement points of the molar on the final tracing and the superimposed initial molar on the final tracing. The skeletal component was represented as the distance between measurement points of the molar on the initial tracing and the superimposed initial molar on the final tracing. The amount and direction of rotation of the maxilla was measured as the angle between SN lines of the superimposed initial tracing and final tracings on superimposition.

A cephalometric analysis derived from the original analysis described by Halazonetis [13] was also performed to evaluate facial mask effects by decomposing T1-T2 changes into condylar growth and total rotation of the mandibular corpus as described in detail [16]. Fig. 2b and c briefly explain the regional superimposition method for this analysis.

As a result of the structural superimposition method, five components were assessed: vector A, vector maxillary skeletal growth; vector B, vector maxillary dentition; vector C, vector condylar growth; vector D, vector mandibular dentition; and vector E, vector mandibular total rotation [13]. Fig. 3a shows graphical vector presentations of movement of the maxillary and mandibular molars. The functional occlusal plane of the final cephalogram was used as an x-axis. The y-axis was perpendicular to the functional occlusal plane through a measurement point of the molar of the initial tracing. The x- and y-components of vectors were measured. Vectors A, C, and E were evaluated in the present study because these vectors were shown skeletal growth.

Statistical methods

Ten subjects were randomly selected to determine the reproducibility of this method. All angular and linear measurements at T1 and T2 and the superimpositional measurements were repeated at least 4 weeks after the first measurements. The combined error and coefficient of reliability were calculated according to Houston [19]. For all measurements, the coefficient of reliability was greater than 90% and was considered to be within acceptable limits.

Student's or Welch's *t* test or the Mann-Whitney *U* test was used to compare T1-T2 changes in the angular or linear values or in each component of the vectors from the structural superimposition method between the FM and pseudo-III groups. In the FM group, Pearson's correlation coefficient or Spearman's rank correlation coefficient was used to evaluate the relationships between T1-T2 changes in angular or linear measurements and each component of the vectors. Statistical analyses were performed using SPSS version 22.0 statistical package (SPSS, Chicago, IL). The level of statistical significance was set at $P < 0.05$.

Results

The means of structural superimpositional measurements of FM and pseudo-III groups are shown in Table 1. FM group exhibited significantly larger x-components of vector A and vector C as compared to pseudo-III group. FM group exhibited significantly smaller y-component of vector C and both x- and y-component of vector E. Fig. 3b shows superimposed graphic vector presentations of the maxilla and mandible for 2 groups.

The means of T1-T2 changes in cephalometric measurements of 2 groups are also shown in Table 2. The FM group exhibited significantly larger changes in ANB angle, convexity, and A-B plane angle. The FM group exhibited significantly larger changes in SNA and Pt A to nasion perp. The FM group exhibited significantly larger negative changes in SNB and SNP angle, facial angle, Ptm’-B’, and Pg to nasion perp.

In the vertical measurements shown in Table 2, the FM group exhibited significantly larger negative changes in FH to the palatal plane and significantly larger changes in maxillary rotation. Negative changes in FH to the palatal plane and positive changes in maxillary rotation represent counter-clockwise rotation of the maxilla. The FM group exhibited significantly larger negative changes in mandibular rotation, which represents total rotation of the mandibular corpus. Negative changes in mandibular rotation represent clockwise rotation of the mandible.

Table 3 shows correlation coefficients between the T1-T2 changes of cephalometric measurements and regional superimpositional measurements in the FM group. Changes in ANB angle, convexity, and A-B plane angle correlated significantly with both the x- and y-components of vector E. Changes in Ptm’-A’ showed a significant correlation with the x-components of vector A. Changes in SNB angle, SNP angle, facial angle, Ptm’-B’, and Pog to nasion perp. correlated significantly with the y-component of vector C and both the x- and y-components of vector E. In vertical measurements, the amount of maxillary rotation and changes in N-Me and Me-ANS correlated significantly with the x-component of vector A.

Discussion

In all vectors and cephalometric measurements with significant difference in values between FM and pseudo-III groups, proper sample size was estimated at 6.93 ~ 27.96 (α (significance level of type I error) = 0.05, ß (significance level of type II error) = 0.20). The number of subjects of FM and pseudo-III groups was 28 and 11, respectively, and was almost consistent with proper sample size.

A large amount of the sagittal component of maxillary skeletal growth correlated significantly with counter-clockwise rotation of the maxilla during facial mask treatment (Table 3). Kambara [10] showed that significant morphological and histological changes in circum-maxillary sutures caused anterior displacement and slight counter-clockwise rotation of the maxillary complex in a study of maxillary protraction appliances on *Macaca irus* monkeys. Excluding animal studies, the present results offer the first demonstration that counter-clockwise rotation of the maxilla increases with the acceleration of maxillary sutural growth due to facial mask treatment in orthodontic patients.

Subjects using a facial mask exhibited a significantly smaller vertical component of condylar growth (Table 1, Fig. 3b), which correlated significantly with inhibition of the forward position of the mandible (Table 3). Applying traction force to the maxillary sutures involves reciprocally pushing on the mandible (as a chincap) through the anchorage provided by the facial mask [2]. Graber [20] reported that subjects with a chincap showed significantly less growth of ramus length. That report seems to support the present results. However, in the present study, some subjects with pseudo-Class III malocclusion may have shown a substantially more forward-upward position of the mandible before treatment because pseudo-Class III malocclusion is characterized by a functional forward shift of the mandible. The forward-upward position could lead to a reduced vertical component of condylar growth. Whether a facial mask could influence condylar growth thus remained unconfirmed in the present study.

Björk and Skieller [14] defined “total rotation” of the mandible as rotation of the mandibular corpus relative to the cranial base, while “matrix rotation” of the mandible was defined as the rotation of the mandibular plane relative to the cranial base. Björk [9] reported that forward (counter-clockwise) total rotation is more frequent than backward (clockwise) total rotation of the mandible during spontaneous growth. However, in this study, subjects using a facial mask exhibited a significantly negative rotational component (Table 1) and mandibular rotation (Table 2), meaning clockwise total rotation, which significantly correlated with inhibition of the forward position of the mandible and correction of sagittal intermaxillary relationships (Table 3). Sugawara et al [21] reported that chincap forces can alter the mandibular form with remodeling of the mandible. In addition, İşcan et al [22] reported that mandibular total rotation increased clockwise in patients with a vertical chincap, whereas total rotation increased counter-clockwise in controls. Such reports seem to support our novel finding that inhibition of counter-clockwise mandibular corpus total rotation may be attributed to facial mask treatment.

The present results suggested that more favorable effects on maxillary sutural growth are accompanied by a larger amount of counter-clockwise rotation of the maxilla. This would induce increased anterior facial height. In clinical relevance, orthodontists should recognize that expected effects of facial mask treatment on maxillary growth might differ between patients with short-face and long-face.

Conclusions

Cephalometric structural superimposition analysis was first used to evaluate facial mask effects. Acceleration of maxillary sutural growth and inhibition of counter-clockwise mandibular corpus total rotation attributed to facial mask treatment may contribute to improvements in Class III malocclusion.

The present results could show that counter-clockwise rotation of the maxilla is increased in accordance with acceleration of maxillary sutural growth due to facial mask treatment.

Ethical approval

The Ethics Committee of the dental collage approved the protocols of this retrospective study (no. 214).

Conflict of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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Figure legends

Fig. 1 - (a) Cephalometric angular measurements. 1, ANB; 2, Angle of convexity; 3, A-B plane angle; 4, SNA; 5, FH-PP; 6, SNB; 7, SNP; 8, Facial angle; 9, Mandibular plane to FH; 10, Gonial angle; 11, Ramus angle; 12, GZN.

(b) Cephalometric linear measurements. 1, N-Me; 2, S-Go; 3, Anterior upper facial height (AUFH); 4, Posterior upper facial height (PUFH); 5, Me-ANS; 6, Go-Ar; 7, Ptm'-A'; 8, Point A to nasion perp.; 9, Ptm'-B'; 10, Pog to nasion perp. The vertical line was perpendicular to the FH plane through the sella. All points for measuring values 1-6 were projected parallel on the vertical line. Each distance between two projected points was measured. Point A and Point B were projected parallel on the line perpendicular to the FH plane through the Ptm, for measurements 7 and 9, respectively. Point A and Pog were projected parallel on the nasion-perpendicular for measurements 8 and 10, respectively.

Fig. 2 - (a) Left, Superimposition of initial (pre-treatment) and final (post-treatment)

tracings on the cranial base; Right, Superimposition of initial and final tracings on the maxillary internal stable structure, the anterior contour of the zygomatic processes.

(b) Superimposition of initial and final tracings on stable mandibular internal structures including the contour of the mandibular canal and any developing tooth buds before root formation.

(c) Superimposition of initial and final tracings of the mandible on the cranial base. On superimposition, the mandible on final tracing with the initial mandibular molar was derotated by an equal amount, but in the opposite direction, using the center of the condyle as the center of rotation.

Fig. 3 - (a) Left, Graphic vector representations of the movement of maxillary molars. Vector A, maxillary skeletal component; Vector B, maxillary dental component. Right, Graphic vector representation of the movement of mandibular molars. Vector C, mandibular condylar growth component; Vector D, mandibular dental component; Vector E, mandibular rotational component. FOP, functional occlusal plane.

(b) Superimposed graphic vector representations of FM and pseudo-III groups. Solid line, FM group; broken line, pseudo-III group. Left, maxillary vectors; Right, mandibular vectors.

Table 1. Comparison of structural superimpositional measurements between the FM and pseudo-III groups. Mean age of T1 and T2 of the pseudo-III group was almost same as that of the FM group. Student's or Welch's *t* test or the Mann-Whitney *U* test was used to compare each component of the vectors between 2 groups.

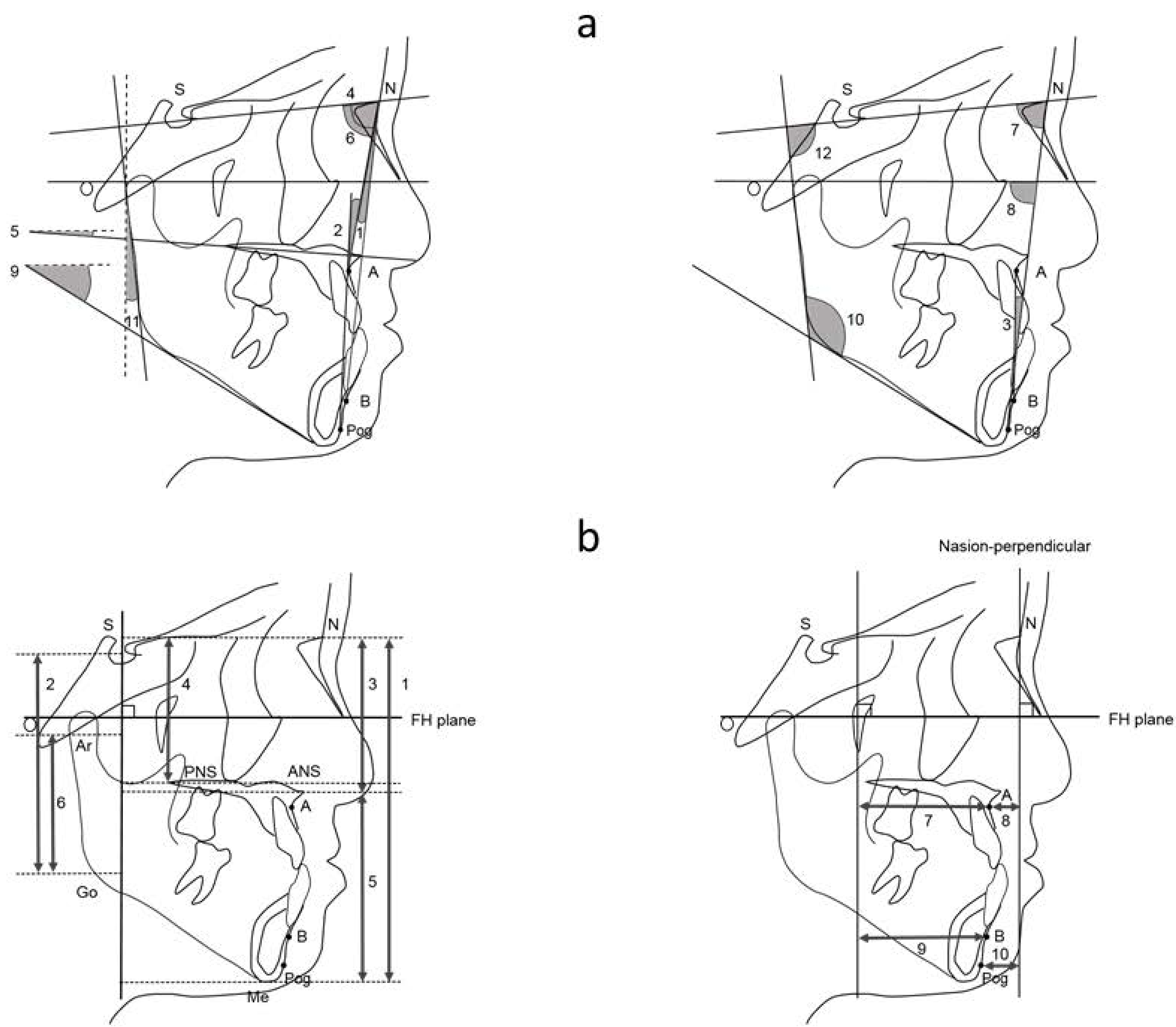
	FM		pseudo-III		
	Mean	SD	Mean	SD	*P* value
Maxillary Skeletal					
VectorA (x) (mm)	2.43	1.39	0.91	0.63	<0.001***
VectorA (y) (mm)	-0.82	0.59	-1.10	0.61	0.349
Mandibular Condylar					
VectorC (x) (mm)	0.98	1.20	0.03	1.03	0.027*
VectorC (y) (mm)	-2.50	1.61	-3.98	1.30	0.010*
Mandibular Rotation					
VectorE (x) (mm)	-0.19	0.61	0.25	0.35	0.032*
VectorE (y) (mm)	-0.52	1.20	0.33	0.70	0.023*

Table 2. Comparison of T1-T2 changes in cephalometric angular and linear measurements between the FM and pseudo-III groups. Mean age of T1 and T2 of the pseudo-III group was almost same as that of the FM group. Student's or Welch's *t* test or the Mann-Whitney *U* test was used to compare T1-T2 changes between 2 groups.

	FM (T1-T2)		pseudo-III (T1-T2)		
	Mean	SD	Mean	SD	*P* value
ANB (°)	2.02	1.22	0.25	0.88	<0.001***
Convexity (°)	3.70	2.37	0.12	1.62	<0.001***
A-B plane (°)	-2.95	1.76	-0.59	1.52	<0.001***
SNA (°)	1.21	0.91	0.32	0.48	<0.001***
FH to palatal plane (°)	-1.12	1.02	-0.10	1.08	0.009**
SNB (°)	-0.82	1.10	0.05	0.85	0.024*
SNP (°)	-0.64	1.01	0.25	0.71	0.012*
Facial angle (°)	-0.46	1.25	0.21	0.53	0.025*
Mandibular pl. to FH (°)	0.69	1.30	0.23	0.99	0.300
Gonial angle (°)	-0.80	1.71	0.25	1.56	0.085
Ramus angle (°)	-1.51	1.50	0.03	1.70	0.008**
GZN (°)	1.69	1.51	-0.08	2.06	0.005**
N-Me (mm)	3.80	1.37	2.77	3.14	0.317
S-Go (mm)	1.20	1.18	1.88	1.51	0.145
AUFH (mm)	1.03	0.79	1.05	1.28	0.951
PUFH (mm)	1.87	0.78	1.05	1.17	0.014*
Me-ANS (mm)	2.30	1.15	1.65	1.55	0.160
Go-Ar (mm)	0.26	1.36	1.09	1.63	0.113
Ptm'-A' (mm)	1.38	0.87	0.78	0.90	0.062
Pt A to nasion perp. (mm)	1.21	0.94	0.24	0.84	0.005**
Ptm'-B' (mm)	-1.08	1.81	0.44	0.81	0.001**
Pg to nasion perp. (mm)	-1.19	2.33	0.14	1.15	0.024*
(Variable of structural analysis)					
Maxillary rotation (°)	2.04	1.35	0.69	0.90	0.004**
Mandibular rotation (°)	-0.52	1.30	0.38	0.82	0.015*

Table 3. Pearson's or Spearman's rank correlation coefficients between T1-T2 changes of cephalometric measurements and superimpositional measurements. *P < 0.05, **P < 0.01, ***P < 0.001.

	VectorA(x)		VectorA(y)		VectorC(x)	VectorC(y)		VectorE(x)		VectorE(y)	
ANB	0.339		-0.341		-0.227	0.373		-0.475	*	-0.564	**
Convexity	0.326		-0.313		-0.235	0.368		-0.483	*	-0.559	**
A-B plane	-0.303		0.404	*	0.236	-0.334		0.465	*	0.548	**
SNA	0.271		-0.217		-0.017	0.002		-0.048		-0.038	
FH to palatal plane	-0.369		0.033		-0.190	0.074		0.117		-0.027	
SNB	-0.164		0.181		0.229	-0.417	*	0.506	**	0.609	**
SNP	-0.144		0.104		0.256	-0.444	*	0.525	**	0.627	**
Facial angle	-0.199		0.018		0.281	-0.499	*	0.518	**	0.579	**
Mandibular pl. to FH	0.115		-0.161		-0.362	0.268		-0.367		-0.427	*
Gonial angle	-0.119		-0.403	*	0.007	0.053		-0.201		-0.140	
Ramus angle	-0.227		-0.318		0.344	-0.159		0.085		0.203	
GZN	0.173		0.166		-0.266	0.057		-0.009		-0.149	
N-Me	0.427	*	-0.359		0.229	-0.446	*	-0.028		0.054	
S-Go	0.099		0.053		0.172	-0.450	*	0.272		0.291	
AUFH	-0.140		0.157		-0.320	-0.170		0.122		0.032	
PUFH	0.258		0.069		-0.023	-0.215		-0.076		0.013	
Me-ANS	0.560	**	-0.142		0.262	-0.307		-0.045		0.063	
Go-Ar	0.029		0.216		-0.161	-0.419	*	0.370		0.297	
Ptm'-A'	0.492	*	-0.012		-0.135	-0.055		-0.064		-0.079	
point A to nasion perp.	0.180		-0.296		0.076	-0.173		0.078		0.072	
Ptm'-B'	-0.085		0.243		0.253	-0.488	**	0.548	**	0.626	**
Pog to nasion perp.	-0.183		0.022		0.282	-0.485	**	0.521	**	0.583	**
(variable of structural analysis)											
Maxillary rotation	0.765	***	0.020		-0.129	-0.134		-0.205		-0.196	
Mandibular rotation	0.245		-0.441	*	0.102	0.770	***	-0.857	***	-0.989	***



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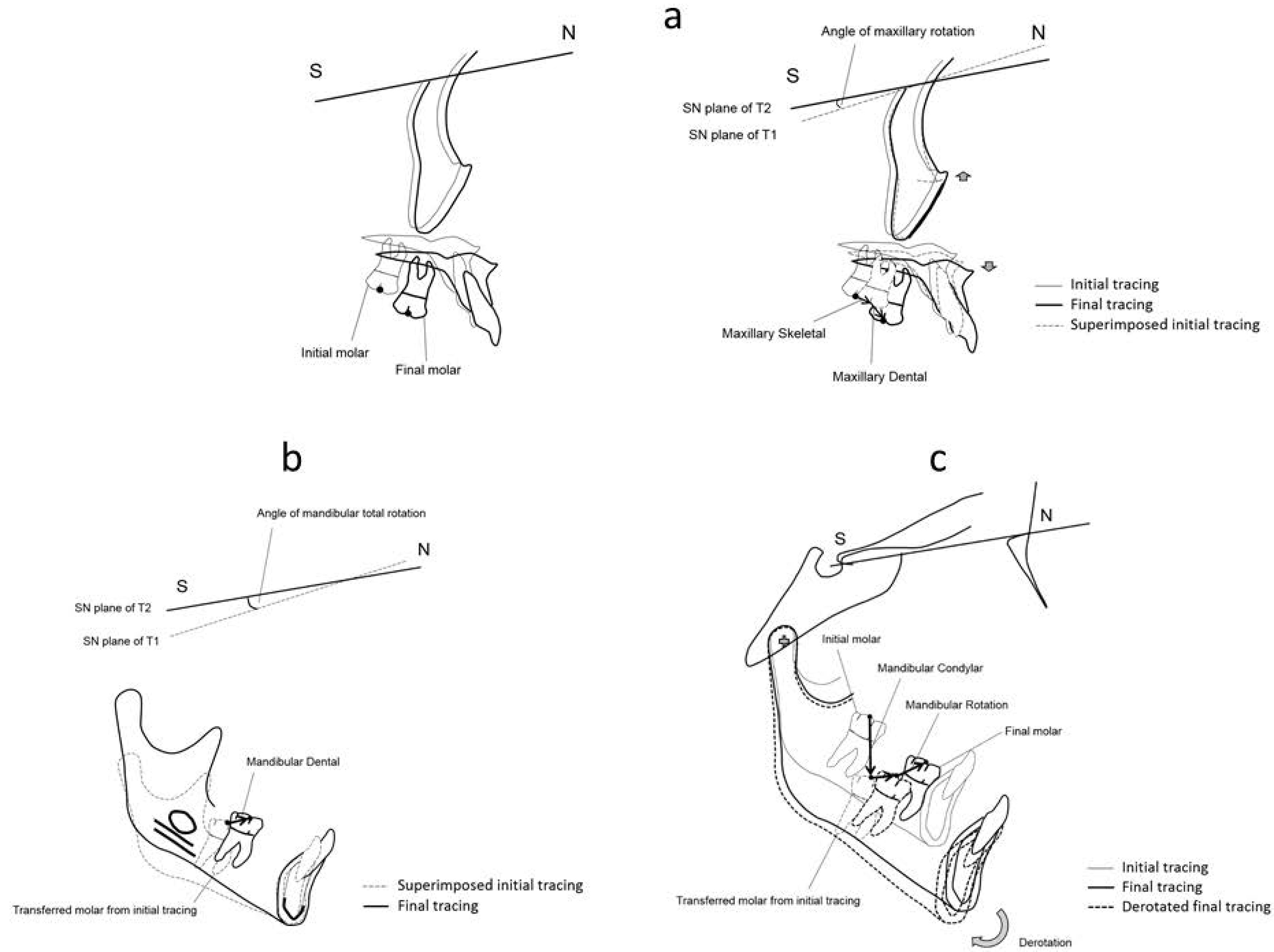

a
N
S
Initial molar
Final molar
Angle of maxillary rotation
N
S
SN plane of T2
SN plane of T1
Maxillary Skeletal
Maxillary Dental
Initial tracing
Final tracing
Superimposed initial tracing
b
Angle of mandibular total rotation
N
S
SN plane of T2
SN plane of T1
Mandibular Dental
Transferred molar from initial tracing
Superimposed initial tracing
Final tracing
c
N
S
Initial molar
Mandibular Condylar
Mandibular Rotation
Final molar
Transferred molar from initial tracing
Initial tracing
Final tracing
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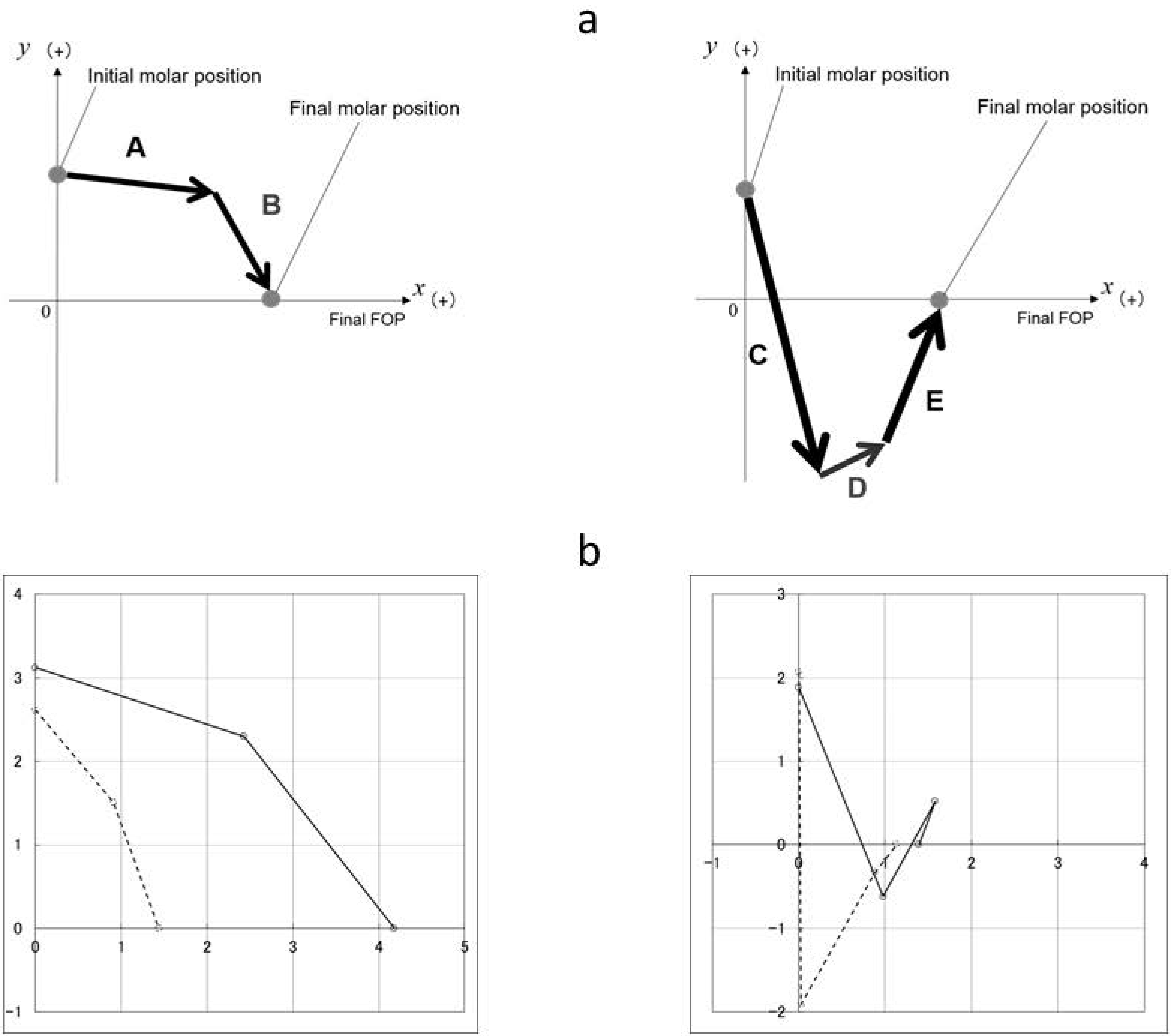
Derotation


a
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Initial molar position
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