Stress change on the temporomandibular joint in mandibular prognathism subjects with asymmetry after orthognathic surgery

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Short title: Stress on TMJ in mandibular asymmetry

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Stress change on the temporomandibular joint in mandibular prognathism with asymmetry after orthognathic surgery

Summary

The purpose of this study was to evaluate changes stress on the temporomandibular joint (TMJ) in 80 Japanese subjects with mandibular prognathism with and without asymmetry after orthognathic surgery using the rigid bodies spring model (RBSM) (The asymmetric group consisted 40 subjects whose Mx-Md midline was >3 degrees. The remaining 40 subjects formed the symmetric group).

The geometry of the stress analysis model was based on frontal cephalograms of the subjects. Menton (Me), the centre point of occlusal force on the line connecting the bilateral buccal cusps of the second molars and the most lateral, superior, and medial points on the condyle were plotted on a computer display and stress on the condyle was calculated with the two-dimensional RBSM program, FORTRAN. The degree (force partition) of the resultant force, the direction (angulation) and the displacement (X, Y) of each condyle were calculated and the horizontal displacement (u), the vertical displacement (v) and rotation (θ) displacement of the mandibular body at Me were calculated pre- and post-operatively.

For the vertical (v) and rotational (θ) displacement, the post-operative value was smaller than the pre-operative value (v: P<0.0001, θ: P=0.0063) in the asymmetry group. For angulation and the X-component, the post-operative value was smaller than that pre-operatively on the deviated (angulation: P=0.0074, X-component: P=0.0003) and non-deviated (angulation: P=0.0024, X-component: P=0.0001) side in the asymmetry group. However, there was no significant difference between the pre- and post-operative value for any parameters, in the symmetry group.

These findings suggest that surgical correction of mandibular prognathism with and without asymmetry could induce an improvement in stress balance on the TMJ in the frontal aspect.

Introduction

Temporomandibular joint (TMJ) internal derangement (ID) is widely reported to be associated with mandibular asymmetry. Schellhas et al. (1990) suggested that disc displacement, ID, or degenerative joint disease could be the main cause of mild and moderate mandibular asymmetry. On the other hand, various studies have investigated occlusal problems as a predisposing factor for TMJ ID. Occlusal instability, midline discrepancy, right-left differences in molar relationship, and inclination of the frontal occlusal plane have been considered to be important occlusal characteristics in patients with TMJ disorders (Solberg et al., 1986; Fushima et al., 1999). Differences in the heights of the right and left rami, have also been suggested as important skeletal problems associated with TMJ pathology (Inui et al., 1999; Trpkova et al., 2000). A similar tendency has been recognized in mandibular prognathism with asymmetry (Ueki et al., 2000), although the incidence of TMJ dysfunction in mandibular prognathism is lower than in mandibular retrognathism (Fernandez Sanroman et al., 1998).

Improvement in TMJ symptoms before and after orthognathic surgery has been discussed in several clinical investigations (Karabouta and Martis. 1985; Kerstens et al., 1989; White and Dolwick. 1992; Hu et al., 2000). In a previous study, it was found that sagittal split ramus osteotomy (SSRO) did not improve anterior disc displacement, while intra-oral vertical ramus osteotomy (IVRO) improved anterior disc displacement for a short post-operative period, and both procedures improved TMJ symptoms (Ueki et al., 2002; 2007a,b). This suggests that TMJ symptoms are not always the resulted disc displacement. In other words, biomechanical change from occlusal and skeletal change may induce improvement in the TMJ.

Most authors agree that the external and internal morphology of a given bone or joint in adults is determined by the biomechanical loads placed upon it during growth. Previous studies have suggested that mandibular asymmetry or occlusal plane inclination could induce TMJ ID due to disturbances in stress on the TMJ (Korioth et al., 1992; Hylander and Johnson, 1997). Paradoxically, there is thesis that an attempt to establish a flat occlusal plane or symmetry can induce a favourable stress balance on bilateral TMJs.

Regarding dynamic analysis, changes in stress on the TMJ after orthognathic surgery using a lateral cephalogram with the rigid bodies spring model (RBSM) have been investigated (Takeuchi et al., 2002; Ueki et al., 2005; 2006). However, when the asymmetry cases were analyzed, it was found that a RBSM program for frontal cephalograms was necessary. Therefore, a program of RBSM for frontal cephalogram and was developed the stress on TMJ in mandibular asymmetry subjects was investigated.

The purpose of this study was to evaluate changes in stress on TMJ in mandibular prognathism subjects with asymmetry after orthognathic surgery using RBSM for frontal cephalograms.

Subjects and Methods

The 80 Japanese adults (21 male and 59 female) in this study presented with jaw deformities diagnosed as mandibular prognathism, with and without asymmetry. The patients ranged in age from 15 to 39 years (mean age 23.7 years, standard deviation, 5.5 years). Informed consent was obtained from the patients and study was approved by Kanazawa University Hospital.

All patients were examined with lateral and frontal cephalograms were obtained of all patients. Cephalograms were taken before surgery (after pre-operative orthodontic treatment) and 3-6 months after surgery. The cephalograms were entered into a computer and analyzed using appropriate computer software (Cephalometric Ato Z, Yasunaga Labo Com, Fukui, Japan). All patients were objectively diagnosed as skeletal Class III from the cephalometric measurements. On the frontal cephalogram, the angle between the ANS-Menton line and a line perpendicular to the bilateral zygomatic frontal suture line was defined as the Mx-Md midline angle. A positive value for this represented mandibular deviation to the left and a negative value mandibular deviation to the right. The Mx-Md midline angles of all cases were then given a positive value so that all consecutive measurements could be attributed to either a deviated or non-deviated side (Ueki et al., 2000). The subjects were divided into a symmetry or asymmetry group according to the Mx-Md midline. The asymmetry group consisted of 40 parents whose Mx-Md midline was >3 degrees, and the remaining 40 as the symmetric group.

Twenty two of the 40 patients in the asymmetry group underwent a Le Fort I osteotomy and intra-oral vertical ramus osteotomy (IVRO), nine a sagittal split ramus osteotomy (SSRO), seven an IVRO and two a Le Fort I osteotomy and SSRO. Twenty four of the 40 patients in the symmetric group underwent SSRO, 11 a Le Fort I osteotomy and SSRO and five IVRO.

Determination of occlusal force center

A system consisting of a pressure-sensitive sheet (Dental Prescale; Fuji Photo Film Co., Tokyo, Japan) and its analyzing apparatus (Dental Occlusion Pressuregraph FPD-705; Fuji Photo Film Co.) connected to a personal computer was used in this study. Data on the reproducibility and the method of calibration has been reported (Maness et al., 1987; Hattori et al., 1994; Harada et al., 2000; Nagai et al., 2001). Each patient was seated with his or her head in an unsupported natural position, looking forward. The pressure-sensitive sheet was placed between the maxillary and mandibular teeth and the patient was instructed to bite as forcefully as possible for approximately 3 seconds. The sheet was read and analyzed using the Dental Occlusion Pressuregraph and the results were put into the computer and visualized on the display screen. The occlusal force centre (only value on the X-coordinate) was determined on the basis of the occlusal balance. The examination was carried out before surgery (after pre-operative orthodontic treatment was done) and 3-6 months after surgery.

Input data for calculations

The most lateral point of the buccal cusp of the lower second molar, Menton, and the most medial, superior, and lateral points on the bilateral condyles on the computer display were plotted, using the frontal cephalogram. Coordinates of the occlusal force centre point was added to the occlusal plane on frontal cephalogram. The mandibular two-dimensional RBSM using the frontal cephalometric data and the occlusal force data were analyzed pre- and post-operatively with the FORTRAN program according to a previously reported method(Takeuchi et al., 2002; Ueki et al., 2005; 2006).

On defining the numerical model, the geometry of the model is based on a frontal cephalogram of each subject (Fig. 1). The entire mandible can be considered as a single rigid element. For the numerical model of the TMJ, the integral points for calculating the contact stress are defined along the contours of the uppermost face of the condyle. The glenoid fossa is assumed to be a rigid element, and the displacement of this rigid element is set to 0 so it may be treated as a supported element (Fig. 2). The occlusal force and its action position are determined using the pressure-sensitive system. Only compressive force is transmitted in a contact surface. Redistribution of negative contact pressure is calculated, according to the following procedures:

Step 1: The contact pressure generated on integration points relative to initially given muscular force is obtained.

Step 2: If negative contact pressure is found on some integral points, it is temporarily removed and a constraint force is added to maintain the balance.

Step 3: As this constraint force does not actually exist, a force equal to this force is added in reverse direction.

Steps 1 and 2 are repeated until the negative contact pressure reduces to a negligible value. The contact pressure distribution without negative contact force can then be obtained.

Finally, as output data, the degree (force partition) of the resultant force, the direction (angulation) and the displacement (X, Y) of each condyle, the horizontal displacement vector (u), the vertical displacement vector (v) and the rotation angle (θ) of the mandibular body at the Me were calculated (Fig. 3).

Analysis was based on the definition that a stable condylar position is one in which the stress is distributed equally over the condylar surface. Once the final calculation had been performed and contact pressure is distributed equally over the condylar surface, any slight mandibular displacement may be disregarded. The displacement from vectors in the initial mandibular position to vectors in the final mandibular position after the calculations can be obtained by conversion calculations from the displacement vector.

This means that the higher the displacement vector, the less clinically stable the mandible and TMJ.

Magnetic resonance imaging assessment

A detailed magnetic resonance imaging (MRI) assessment of each pair of TMJs was performed using a 1.5-Tesla MRI system (Signa Scanner, General Electric Medical Systems, Milwaukee, Wisconsin, USA), with bilateral 3-inch dual surface coils with the jaw in the closed, resting and maximally open position. An initial axial localizer was introduced to obtain exact midcondylar sections perpendicular and parallel to the long axis of each condyle. Images of the bilateral orthogonal sagittal planes and coronal planes of the TMJs in the closed jaw position were acquired first with a repetition pulse (T_R) of 2000 mseconds, echo times (T_Es) of 20 mseconds, a 3-mm image slice thickness, and a field of view of 10 cm. Images of the bilateral sagittal planes of the TMJs in the open mouth position were then obtained with a T_R of 1000 mseconds and T_Es of 20 mseconds. The incidence of anterior disc displacement with reduction (ADDwR) and without reduction (ADDwoR) were examined pre- and post-operatively.

Statistical analysis

Data were compared between the groups with non-paired t-test and between pre- and post-operative value with paired t-test using the Stat View™ version 4.5 software program (Abacus Concepts, Inc., Berkeley, California, USA). The differences were considered significant at $p<0.05$.

Results

There were significant differences post-operatively compared with pre-operatively in the asymmetric group in the Mx-Md midline (P<0.0001) and occlusal cant (P<0.0001), but not in the symmetric group.

For vertical (v) and rotational (θ) displacement, post-perative value were smaller than pre-operative values (v: P<0.0001, θ: P=0.0063) in the asymmetric group. For angulation and X-component, the post-operative value was smaller than the pre-operative value at the deviated (angulation: P=0.0074, X-component: P=0.0003) and non-deviated (angulation: P=0.0024, X-component: P=0.0001) side in the asymmetric group. However, there was no significant difference between the pre- and post-operative values in any parameter in the symmetric group (Tables 1 and 2).

Comparison between the deviated and non-deviated side showed no significant differences in resultant force (P=0.0054), angulation (P=0.0095), X-component (P=0.0001) and Y-component (P=0.0043) in the asymmetric group pre-operatively. There were significant differences in resultant force (P=0.0372), X-component (P<0.0001) and Y-component (P=0.0354) in the symmetric group pre-operatively. However, in the symmetry group, no significant differences were found for any parameters post-operatively. On the other hand, in the asymmetric group, significant differences remained in angulation (P<0.0001) and X-component (P=0.0004) post-operatively (Tables 1 and 3).

In symmetric group, two joints with pre-operative ADDwoR did not change post-operatively. On the deviated side in the asymmetric group, 22 joints with pre-operative ADDwoR and eight joints with pre-operative ADD changed to 16 joints with ADDwoR and 10 joints with ADDwR post-operatively. On the non-deviated side in the asymmetric group, three joints with preoperative ADDwoR and two joints with pre-operative ADDwR changed to three joints with ADDwoR and no joint with ADD post-operatively.

Discussion

Anterior disc displacement has been observed mostly at the deviated side in patients with mandibular deviation (Link and Nickerson. 1992; Kobayashi et al., 1999). Other authors have shown that in mandibular prognathism with asymmetry there is a higher incidence of disc displacement on both sides (56 and 66.7 %) (Ueki et al., 2000; Yamada et al., 2001), whereas minimal displacement is seen in patients with simple mandibular prognathism (18.2%) (Ueki et al., 2000). TMD is associated with disturbed facial skeleton growth such as mandibular deviation in rabbits or in humans (Trpkova et al., 2000; Schelhas et al., 1993; Isberg and Legrell, 2000). Some authors have reported TMJ ID as a primary cause of growth disturbance, including mandibular asymmetry (Schelhas et al., 1993; Hans et al., 1992). In vivo experiments of disc displacement in rabbits have also verified that permanent articular-disc displacement is one causal factor in the development of mandibular midline asymmetry (Legrell and Isberg, 1999). However, some studies have suggested that disc displacement does not always induce mandibular asymmetry. Occlusal instability, midline discrepancy, right-left differences in molar relationship, and inclination of the frontal occlusal plane have been considered to be important occlusal characteristics in patients with TMJ disorders (Solberg et al., 1986; Fushima et al., 1999; Inui et al., 1999; Trpkova et al., 2000).

Improvement in TMJ symptoms after orthognathic surgery has been reported in several clinical investigations. Kerstens et al. (1989) observed post-operative improvement in 66 percent of patients who underwent orthognathic surgery and White and Dolwick (1992) 89.1 percent. Similar data were found by Karabouta and Martis (1985). Hu et al. (2000) reported post-operative improvement in only 30 percent of patients who had undergone SSRO but in 75 percent who had undergone IVRO. Previous studies (Ueki et al., 2002; 2007a) have also suggested that SSRO either with or without a Le Fort I osteotomy cannot alter the pre-operative disc position, including anterior disc displacement, although these procedures can improve the symptoms of TMJ dysfunction. IVRO with or without a Le Fort I osteotomy could improve anterior disc displacement (ADD) and TMJ symptoms along with condylar position and angle change. However, it is difficult to predict the amount of improvement in ADD (Ueki et al., 2002; 2007b).

This study investigated the dynamic calculation using geometric information from frontal cephalograms so that the comparison between surgical procedures could not be taken into account. The purpose was to clarify the theoretical contact stress on the TMJ on the basis of geometric information alone, using a single calculation technique. Therefore, although differences in surgical procedure, fixation method and setback amount would influence the stress on the TMJ, the overall skeletal morphology analyzed in this study was considered to be geometric information obtained that includes these factors. An attempt was made here to develop a model to describe in this study.

Some finite element models (FEMs) of the TMJ have been developed to simulate condylar motion or stress change (Koolstra et al., 1988; Korioth and Hannam. 1990; Korioth et al., 1992; Chen and Xu. 1994; Tanaka et al., 1994; Tanne et al., 1996; Devocht et al., 1996; Hylander and Johnson. 1997). However, in FEM, data on many material properties are necessary. FEMs are suitable for calculating stress within elements, while the RBSM method is used for calculating the surface force between elements. This theory has been used to analyze stress on the knee, hip, and wrist in the field of orthopaedic surgery (Schuind et al., 2005; Genda et al., 2005). For this reason, FEM was not used rather RBSM was employed because many individual images had to be analyzed to provide a more comprehensive biomechanical description of the loading and the results had to be suitable for statistical analysis. Finally, as the amount of data collected was large simple analysis was required.

From the results of FEMs, Buranastidporn et al. (2006) concluded that the symptomatic sides were significantly related to the degree of inclination of the frontal occlusal plane and increasing its angulation resulted in a decrease of symptoms on the ipsilateral and an increase on the contralateral sides. In their asymmetric-mandibular models, both TMJs were fixed in the same position and remained symmetric in shape. Ten asymmetric models were created with the frontal occlusal plane and frontal mandibular plane inclined by 1-10 degrees in 1 degree increments ascending to the left side

(Buranastidporn et al., 2006).

However, the TMJ structure in jaw deformity patients is different from that in subjects with a normal TMJ. Especially, an asymmetric mandible has the two different TMJs (Ueki et al., 2000). It was not realistic that in an asymmetric-mandibular model, both TMJs remained symmetrical in shape. Therefore, when TMJ stress analysis is performed, outline data derived from more realistic morphology of TMJ is more appropriate to calculate the contact stress.

A previous study (Ueki et al., 2005) using RBSM for sagittal tomography demonstrated that TMJ stress was associated with TMJ morphology in Class III patients whether or not they were asymmetric. There was also a significant correlation between disc position and stress angulation. In the asymmetric group, regression analysis indicated a significant correlation between the difference in stress angulation (between the deviated side and non-deviated side) and the degree of asymmetry (measured by the angle of asymmetry). These results proved that TMJ morphological adaptation was strongly associated with occlusion and skeletal morphology.

In a study (Ueki et al.,2006) using RBSM for lateral cephalogram before and after setback surgery, when muscular power was assumed to be 1, the post-operative degree of the force vector was higher than the pre-operative value. The X-coordinate u and rotation θ of the displacement vector in the pre-operative patients with mandibular prognathism were significantly greater than those in the control subjects. However, there were still significant differences between the displacement values of the post-operative patients and those of the control subjects. The results of the displacement suggested that the condyles of subjects with normal skeletal relations and occlusions were dynamically more stable than those of subjects with mandibular prognathism.

When the frontal occlusal plane increased in the FEM using frontal cephalogram, on the ipsilateral side, the distribution showed a marked shift in direction, and the medial portions were loaded least, with the stress to the lateral part gradually increasing. For the contralateral disc, the medial borders were additionally loaded. The mean stress values on the ipsilateral (shifted) disc were smaller than those in the standard model and those on the contralateral side (Buranastidporn et al., 2006).

In contrast, in this study using RBSM, the resultant force on the deviated side was larger than that on the non-deviated side, in both groups. There was a significant difference in stress angulation between the deviated and non-deviated side but only in the asymmetric group. Although there was no significant difference in stress angulation between either side in the symmetric group, that on the deviated side, was significantly larger than that on the non-deviated side. Furthermore, although stress angulation on the bilateral condyles tended to incline to the opposite side in the symmetric group, in the asymmetric group it tended to incline to the same (deviated) side. This tendency in stress angulation might promote mandibular asymmetry. Vertical displacement in the asymmetric group was larger than that in the symmetric group. This suggests that the symmetric mandible was more stable as an element in the vertical dimension of the asymmetric group. On the other hand, the X-component of the symmetric group was significantly smaller than that of the asymmetric group. This could imply that both condyles in the symmetric group were more dynamically stable than those in the asymmetric group in the horizontal dimension.

A comparison of the pre- and post-operative values revealed no significant change in the symmetric group. In contrast, the post-operative value became smaller than the pre-operative value, during vertical (v) and rotational (θ) displacement of the mandible, and angulation and X-component in both TMJs. This suggests that the direction of the inclined force was upwards on both sides following surgical correction and both condyles were more dynamically stable in the asymmetric group in the horizontal dimension. The pre-operative significant differences in three parameters between the deviated and non-deviated sides in the symmetric group were not found post-operatively. On the other hand, although there were significant differences in all four parameters between the deviated and non-deviated sides in the asymmetric group pre-operatively, significant differences in angulation and the X-component remained post-operatively. This suggests that the difference between the right and left sides could also improve after surgery in the symmetric group, however it could not improve completely in the asymmetric group. The frontal cephalograms 3-6 months post-operatively were used in this study. Therefore, it was considered that the shapes of the bilateral condylar surface that adapted the pre-operative mandibular asymmetry did not change immediately after surgery and was not dynamically stable within this period. Since the purpose of this study was to examine the change following surgery, there was only one registration after surgery. However, more information including the remodelling process would have been gained if the registrations had been done eg. one, three and 12 months after surgery and even after a longer period of follow-up.

Conclusions

The findings suggest that surgical correction of mandibular prognathism with and without asymmetry could induce improvement in stress balance on bilateral TMJs on the frontal view.

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Legends

Figure 1. Rigid bodies spring model (numerical model). The geometry of the model is based on a frontal cephalogram of each subject.

Figure 2. (a) Integral points on codylar surface.(b) Spring model between condylar surface and glenoid fossa. The integral points for calculating the contact stress are defined along the contours of the uppermost face of the condyle. The glenoid fossa is assumed to be a rigid element. Kn shows spring coefficient in the calculation.

Figure 3. Results of rigid bodies spring model calculation. (a)Pre-operative, (b) Post-operative. The degree (force partition) of the resultant force, the direction (angulation) and the displacement (X, Y) of each condyle, the horizontal displacement vector (u), the vertical displacement vector (v) and the rotation angle (θ) of the mandibular body at the Me were calculated

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Fig. 1

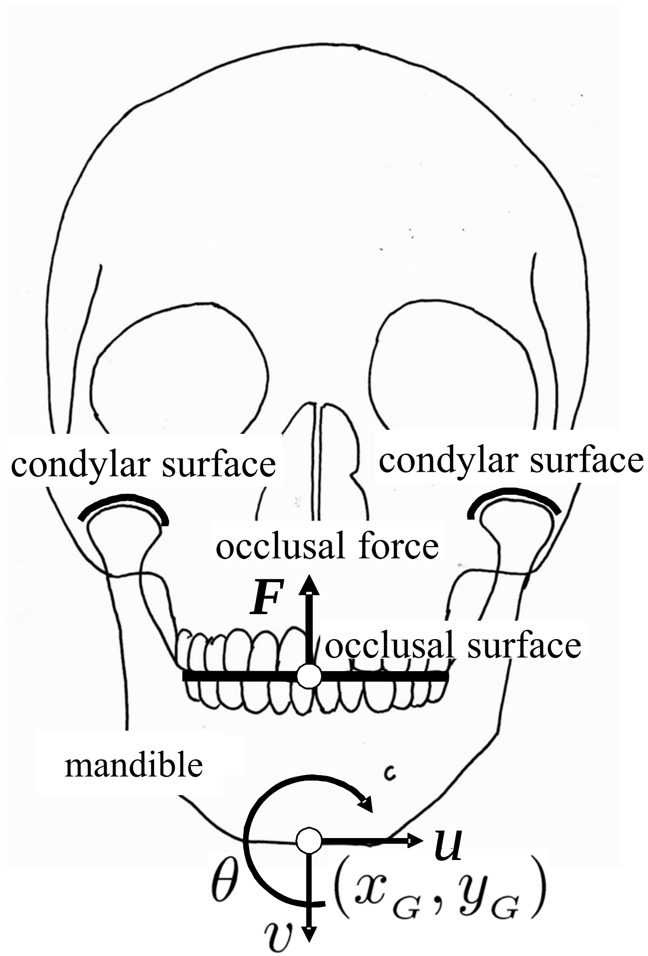

condylar surface
condylar surface
occlusal force
F
occlusal surface
mandible
u
θ
(x_G, y_G)
v

Fig. 2

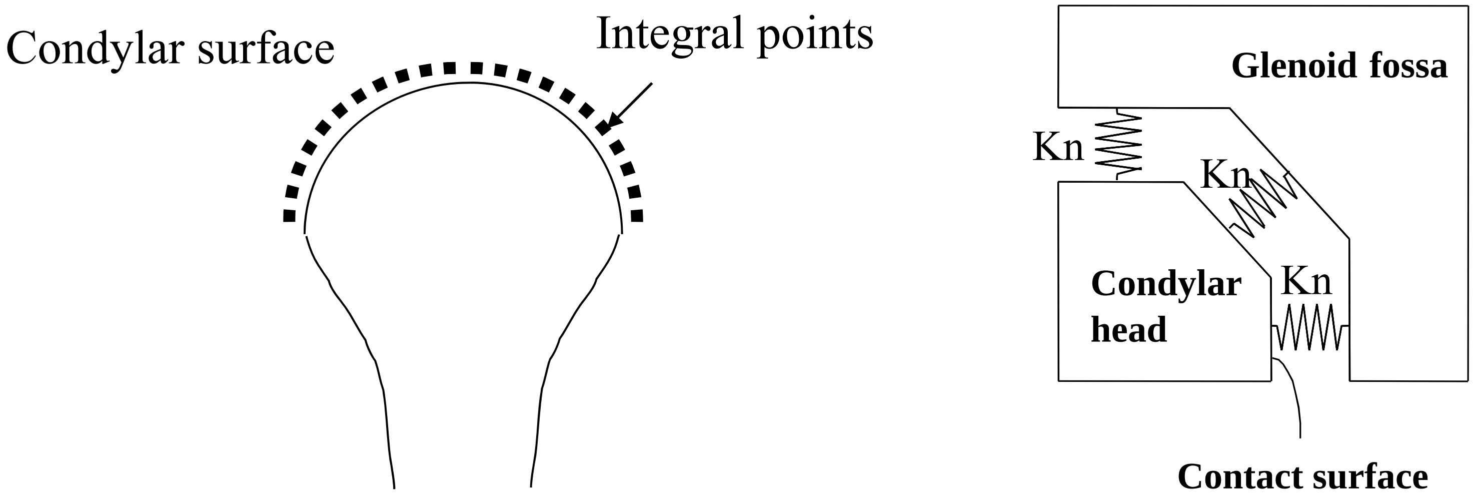
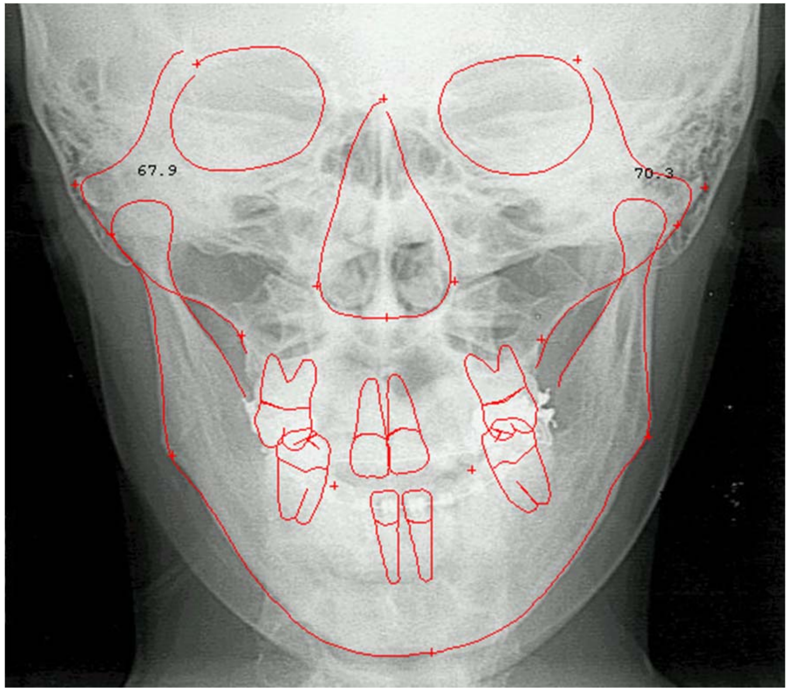
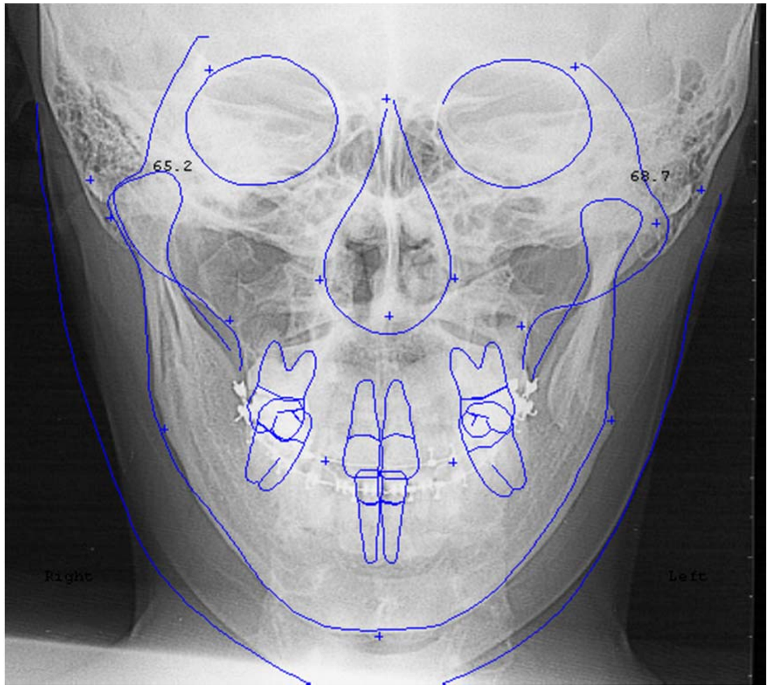

Condylar surface
Integral points
Glenoid fossa
Kn
Kn
Kn
Condylar head
Contact surface

Fig. 3

A



B



Displacement of mandible	(u)	0.01287		
	(v)	0.00983		
	(θ)	0.00003		
Force on condyle	Deviated side		Non-deviated side	
	Resultant force	0.296	Resultant force	0.705
	Angulation	3.864	Angulation	9.617
	X-component	0.020	X-component	0.118
	Y-component	0.296	Y-component	0.695

Displacement of mandible	(u)	-0.00288		
	(v)	0.01292		
	(θ)	-0.00001		
Force on condyle	Deviated side		Non-deviated side	
	Resultant force	0.528	Resultant force	0.472
	Angulation	-0.980	Angulation	1.730
	X-component	-0.009	X-component	0.014
	Y-component	0.528	Y-component	0.472

Table 1. Results of parameters. u: horizontal displacement, v: vertical displacement, θ: rotational displacement.

						Deviated side				Non-deviated side				Mx-Md Midline	Occlusal cant
			(u)	(v)	(θ)	Resultant force	Angulation	X-component	Y-component	Resultant force	Angulation	X-component	Y-component		
Symmetric group	Pre-operative	Mean	-0.0007	0.0107	-3.4E-06	0.5317	-1.3774	-0.0137	0.5309	0.4699	2.4372	0.0207	0.4684	1.5473	-0.5765
		SD	0.0047	0.0013	1.46E-05	0.0908	2.9148	0.0264	0.0908	0.0905	4.1511	0.0313	0.0907	1.3753	2.1074
	Post-operative	Mean	-0.0023	0.0127	-1.1E-05	0.5034	-0.7218	-0.0078	0.4981	0.5072	0.8842	0.0095	0.5016	0.9823	-0.3218
		SD	0.0158	0.0097	6.92E-05	0.0624	7.7137	0.0783	0.0561	0.0604	7.9991	0.0788	0.0561	1.6569	2.4631
Asymmetric group	Pre-operative	Mean	-0.0015	0.0117	-1.1E-05	0.5682	10.9476	0.0138	0.5661	0.4344	6.0741	0.0506	0.4286	6.8570	-2.5080
		SD	0.0064	0.0016	2E-05	0.1438	38.3450	0.0455	0.1442	0.1430	8.0671	0.0517	0.1423	3.5046	2.5800
	Post-operative	Mean	-0.0002	0.0089	-9.8E-07	0.5170	-2.7586	-0.0228	0.5154	0.4855	1.7315	0.0148	0.4841	0.6477	0.8867
		SD	0.0024	0.0017	7.23E-06	0.0866	3.7466	0.0331	0.0869	0.0869	4.2991	0.0343	0.0872	2.6956	3.1915

Table 2. Comparisons between pre and postoperative value in symmetry group and asymmetry group. Data shows p-value. *:Significant difference shows at p<0.05.

	(u)	(v)	(θ)	Deviated side Resultant force	Angulation	X-component	Y-component	Non-deviated side Resultant force	Angulation	X-component	Y-component
Symmetric (pre) versus Asymmetric (pre)	0.5380	0.0035 *	0.0669	0.1795	0.5170	0.0014*	0.1952	0.1881	0.5546	0.0024 *	0.1400
Symmetric (post) versus Asymmetric (post)	0.4234	0.0171 *	0.3665	0.3692	0.0132*	0.2551	0.2487	0.1650	0.5608	0.7016	0.2444
Symmetric (pre) versus Symmetric (post)	0.5414	0.2132	0.5164	0.1289	0.5170	0.6461	0.0701*	0.0441*	0.2846	0.4243	0.0664
Asymmetric (pre) versus Asymmetric (post)	0.2753	<0.0001*	0.0063*	0.0719	0.0074*	0.0003*	0.0746	0.0718	0.0024*	0.0001 *	0.0500

Table 3. Comparisons between deviated side and non-deviated side. Data shows p-value. *:Significant difference shows at p<0.05

		Resultant force	Angulation	X-component	Y-component
Deviated side vs Non-deviated side	Symmetric (pre)	0.0372*	0.2846	<0.0001*	0.0354 *
	Symmetric (post)	0.8328	0.5170	0.4842	0.8455
	Asymmetryic(pre)	0.0054*	0.0095 *	0.0001 *	0.0043 *
	Asymmetric (post)	0.2640	<0.0001*	0.0004 *	0.2679