Comparison of the stress direction on the TMJ in patients with class I, II, and III skeletal relationships.

Comparison of the Stress Direction on the TMJ in Patients with Class I, II, and III Skeletal Relationships

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Structured abstract

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Objective- The purpose of this study was to assess the relation between skeletal morphology and stress direction on the temporomandibular joint (TMJ) by a two-dimensional rigid body spring model (RBSM).

Designs- Lateral cephalograms were analyzed and the information was processed with a FORTRAN analysis program.

Setting and Sample Population- The subjects were 149 patients (54 men and 95 women, mean age 21.8±5.9 years) from Kanazawa University Hospital and the School of Dentistry, Virginia Commonwealth University. These 149 cases consisted of 48 that were skeletal Class I, 54 that were Class II, and 47 that were Class III. These patients had no TMJ symptoms or abnormalities.

Outcome measure- The force vector on the condyle, its direction (**Ph angle**), the degree of the vector (**Ph**) and the displacement vector (**u, v**), and the rotational angle (**θ**) of the mandibular body were calculated by RBSM.

Results- The direction of the force vector (Ph angle) on the condyle was 24.83° ± 4.67° in the Class II group, 21.04° ± 5.59° in the Class I group, and 19.58 ± 7.57° in the Class III group. The Ph angle of the Class II group was significantly larger than those of the Class I and III groups ($P<0.05$).

Conclusion- This study suggests that differences in skeletal patterns induce differences in stress distribution on the TMJ; the morphology of the TMJ was also associated with stress direction and distribution on the condyle.

Key words: temporomandibular joint; stress direction; rigid body spring model

Introduction

Although it is very important to clarify the relationship between dentofacial structure and temporomandibular joint (TMJ) structure, few studies of dentofacial structure relative to temperomandibular dysfunction (TMD) have been reported. In skeletal Class III cases, we have found that patients with different malocclusions or dentofacial deformities often have different TMJ morphologies (1). Furthermore, it was found that mechanical stress on the TMJ also varied with the individual TMJ morphology (2).

Most studies agree that the external and internal morphology of a given bone or joint in an adult is determined by the biomechanical loads placed upon it during growth (3-5). These loads arise from the functioning of the associated musculature. O'Ryan and Epker have demonstrated different loading characteristics of the TMJ associated with different skeletal patterns (6). Through examination of the trabecular patterns of condyles from Class I, Class II open bite, and Class II deep bite skeletal patterns, they deduced the vectors of condylar loading in the functioning joint. They found that the functional loading patterns in these cases were significantly different. If the function loading patterns of the TMJ is different in different skeletal patterns, it is likely that the structural relationship is also different. However, their study examined only the trabecular pattern of the condyle and did not deal with the intra-articular disc. Furthermore, no dynamic analysis was performed.

On the other hand, it has been reported that the incidence ratio of internal derangement and anteriorly displaced discs in skeletal class II cases was greater than in Classes I and III cases (7). This may be explained by the relationship between dentofacial structure and TMJ structure on basis of the dynamic theory.

Several theoretical approaches have been used in an attempt to understand various aspects of TMJ biomechanics (8-13). Some finite element models (FEMs) of the TMJ have been developed to simulate condyle motion or stress change. However, the geometry of the FEMs were based on only one representative image of the TMJ, while in fact data on many material properties were needed. For this reason, FEM was not an appropriate technique for this investigation. Instead, a stress distribution analysis method, using the rigid body spring model (RBSM) was employed because many individual images had to be analyzed to provide a more comprehensive biomechanical description of the loading. In addition sufficient results had been obtained that were suitable for statistical analysis. Finally, large amounts of data were collected for which a simple analysis was required.

The purpose of this study was to assess the relation between skeletal morphology and stress direction on the temporomandibular joint (TMJ) by a two-dimensional rigid-body spring model (RBSM) and to consider how these factors relate to the incidence of anterior disc displacement.

Patients and Methods

Subjects

The subjects were 149 patients (54 men and 95 women, mean age 21.8±5.9 years) from the hospital of the School of Medicine, Kanazawa University and the School of Dentistry, Virginia Commonwealth University. These 149 cases consisted of 48 skeletal Class I cases (28 men and 20 women, mean age 24.2±1.7 years), 54 Class II cases (17 men and 37 women, mean age 18.9±7.1 years), and 47 Class III cases (9 men and 38 women, mean age 22.1±6.0 years). Class I subjects were volunteer without orthodontic treatment. Class II and III subjects were selected at random from the patients underwent orthodontic and orthognathic treatment. All subjects were in accordance with this study. The patients had no TMJ symptoms or abnormalities.

Methods

All patients were examined with lateral cephalograms. The cephalograms were entered into a computer with a scanner (GT9500, Epson, Tokyo, Japan) and analyzed using appropriate computer software (Cephalometric Ato Z, Yasunaga Labo Com, Fukui, Japan) (Fig. 1). The skeletal classifications were objectively determined from the cephalometric measurements (Table 1). Finally, the Ricketts method was used to discriminate between skeletal I, II and III cases. In addition, the first molar, gonial angle, and the most anterior, superior, and posterior points on the condyle on the computer display and the mandibular two-dimensional RBSM were analyzed with the FORTRAN program according to our method previously reported (Fig. 2) (14).

Calculations

Calculation was performed according to our previous report (14).

The force vector resulting from the power generated by the masticatory muscle (Pm) was defined as 1 in the calculations. This force vector was placed on the gonial angle point. Simultaneously, the values of the direction vector (Ph angle), the degree of the resultant force vector (Ph) on the condyle, and the displacement vector (u, v) and rotation angle (θ) of the mandibular body were also calculated. Note that the resultant force vector of muscular power is different from the displacement vector, although both vectors seem to be in the same place on the gonial angle. The displacement vector is the coordinate conversion vector in this calculation process.

The software program was modified so that the results of the simulation could be seen as an image on a personal computer (Fig. 3). The analysis was based on the definition that a stable condylar position is one in which the stress is distributed equally over the condylar surface. When the final calculation had been performed and contact pressure was 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 presented by conversion calculations from the displacement vector. This means that the higher the displacement vector, the less clinically stable the mandible and the TMJ are.

Each parameter measured exhibited the following physiological features:
Stress on the condyle during maximum occlusal force (Ph)
Stress direction on the condyle during maximum occlusa force (Ph angle)
Horizontal stabilization of the mandible; a positive value shows a tendency for movement of the mandible in an anterior direction (u)
Vertical stabilization the mandible; a positive value shows a tendency for movement of the mandible in a superior direction (v)
Rotational stabilization of the mandible; a positive value shows a tendency for movement of the mandible in a counter-clockwise rotatation (θ)

Statistical analysis

Statistical analysis for differences in the force vector degree (Ph), directional value (Ph angle), and displacement coordinates (u, v) and rotation angle (θ) between the three patient groups was performed with the Stat View™ version 4.5 software program (ABACUS Concepts, Inc., Berkeley, CA). Scheffe's F test (a multiple comparison procedure) was selected to compare the difference between 3 groups who consisted of different data number. The differences were considered significant at $p<0.05$.

Results

The results of the cephalometric analysis are shown in Table 1. Significant differences in SNB and mandibular length ($P<0.05$) between the groups were shown. The skeletal patterns of the three groups were shown to be significantly different.

The direction of the force vector (Ph Angle) on the condyle was , 21.04° ± 5.59° in the Class I group, 24.83° ± 4.67° in the Class II group, and 19.58 ± 7.57° in the Class III group. The Ph angle in the Class II group was significantly larger than those in the Class I and III groups ($P<0.05$) (Fig. 4).

The mean value of the resultant force vector degree (Ph) in the Class I group was 0.653 ± 0.052 and in the Class II group it was 0.619 ± 0.051, a significant difference ($p<0.05$). The value in the Class III group was 0.640 ± 0.080. For these calculations, the value of the resultant force vector of muscular power was defined as 1 (Fig. 5).

The value of the X-coordinate component u of the displacement vector was the highest (0.093 ± 0.077) in the Class III group, 0.039 ± 0.136 in the Class I group, and -0.022 ± 0.061 in the Class II group. A significant difference was noted between the groups in the value u of the displacement vector ($p<0.05$).

The value of Y-coordinate component v of the displacement vector was 0.666 ± 0.092 in the Class I group, 0.682 ± 0.107 in the Class II group, , and 0.713 ± 0.147 in the Class III group. There was no significant difference between the groups in the value v of the displacement vector.

The value of the rotation component θ of the displacement vector was the highest (7.787± 6.635) in the Class III group, 1.699 ±4.935 in the Class I group, and -1.760 ± 5.310 in the Class III group. There was a significant difference between the groups in the value of the rotation component θ of the displacement vector (Fig. 6).

Discussion

The RBSM theory was incorporated into a model devised as a discrete method for analyzing R-R-type-interface problems (where the two bodies bonded by an interface are both rigid). This theory assumes that an element itself is a rigid body. The model represents a method for calculating and measuring the concentration of energy, based on the force exerted on a bundle of springs distributed along the boundary of the element. This force is compared with the finite element method (FEM), which is commonly used in the field of dentistry (10-13). The RBSM theory is simple and useful because this simple calculation can be carried out rapidly with only a small amount of information compared with FEM. Even if a large amount of information was obtained, this could be used to extrapolate to an *in vivo* situation, which would support the validity of statistical accumulation of clinical finding. The FEM is suitable for calculating stress within elements, while the RBSM theory 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 (15, 16). These studies clearly demonstrate that RBSM can provide reliable results.

The simplicity of the RBSM calculation may suggest that the result and interpretation of the RBSM may not be of sufficient clinical and biological relevance. However, even using more complex calculations accurate verification of such findings may not be possible. Therefore, we think that it is of greater clinical use to define the greatest correlation between the anatomical morphology and its reflected dynamic adaptation and this type of dynamic calculation.

The subjects of the study comprised individuals selected from both Japanese and American populations, and included male and female subjects of various ages. However, the purpose of this study was to clarify the theoretical natural occurrence of the TMJ anatomical structure on the basis of geometric information alone, using a single calculation technique. Therefore, although racial, sexual and chronological differences would influence craniofacial skeleton, the overall skeletal morphology analysed in this study is considered to be the geometrical information obtained inclusive of these factors. We would like to stress that the theoretical relation between the craniofacial skeleton and TMJ structure alone was described in this study.

In this study, the resultant force in the Class II group was smaller than that in the Class I group. However, real masticatory force was so variable that it was difficult to evaluate the degree of load on the condyle. If the real occlusal force could be obtained, a more realistic evaluation could be performed.

On the other hand, this study demonstrated that the stress direction on the condyle in the Class II patients was more anterior than in the Class I and III patients. The stress direction in the Class III group was more forward in comparison to that in the Class I and III groups (Fig. 7). This result might make it possible to examine the relationship between the original disc position and skeletal pattern, on the basis of the dynamic principle.

Disc displacement is a common abnormality seen on images of the TMJ. Usually the displacement is anterior, anterior lateral, or anterior medial. In the normal joint, the posterior band of the biconcave disc is located superior to the condyle in the closed-mouth position (17-21). Normal disc position had been defined in previous studies without reference to the skeletal pattern and occlusion (22,23).

Fernandez et al. found that the incidence of disc displacement was 11.1% in a Class I anterior open-bite group and 10% in a Class III group. When the Class II group was investigated, a displaced disc was diagnosed in 15 of the 28 joints (53.6%) (7). Schellhas et al. presented 100 patients with a retrognathic facial skeleton in whom the TMJs were analyzed with the aid of magnetic resonance imaging for signs of moderate to severe pathology (24). He found that a Class II dentofacial deformity was strongly associated with moderate to severe TMJ pathology or an anteriorly displaced disc. The degree of joint degeneration directly paralleled the severity of the retrognathia.

An increased prevalence of disc displacement has been found in patients with mandibular retrognathia presenting for orthognathic surgery. Link and Nickerson studied 39 patients referred for orthognathic surgery, 38 of whom were found to have disc displacement before surgery (25). All open-bite patients and 88% of the patients with a Class II malocclusion had bilateral disc displacement.

However, images different from those found in normal joints have been recognized in patients with Class III malocclusions (1). The magnetic resonance images of the TMJ discs differed from the normal images previously reported. Classification of the disc position in skeletal class III patients based on magnetic resonance imaging has been reported (1). Three types of disc position could be identified by means of magnetic resonance imaging in addition to anterior displacement with or without reduction: anterior, fully-covered, and posterior. Although the anterior type is the typical image of a normal joint, the fully covered and posterior types were found in Class III cases. It was also demonstrated that TMJ stress was associated with changes in TMJ morphology in Class III patients (2).

In summary, according to these reports, the joint disc in Class II cases is typically more anterior than in Class III cases, and there is a relationship between skeletal morphology and TMJ morphology including a dynamic environment.

If the disc acts as a shock absorber, it would naturally be anterior in Class II cases, as previously reported. In other words, it was impossible to judge whether the disc position was normal without assessing the skeletal and occlusal patterns. Anterior disc position has been highly correlated with Class II skeletal pattern and Class II patients have a greater risk of such anterior disc displacement.

Schellhas et al. concluded that TMJ disc displacement is common in cases of mandibular retrusion and leads to changes in facial morphology in a high percentage of patients (24). However, our study, using dynamic analysis, suggested that skeletal morphology could also lead to anterior disc position or displacement.

If the change in loading within the joint is greater than the plasticity of the tissues resulting from concentration of the stress, the joint is unable to adapt to this increased loading and tissue breakdown, such as disc perforation and condylar resorption may result (26). In the study of Beek et al (27), the disc moved together with the condyle in the anterior direction but without a similar movement of ligaments or the lateral pterygoid muscle. By adapting its shape to the changing geometry of the articular surfaces, the disc prevented small contact areas and thus local peak loading. Therefore, the outcome indicated by this RBSM calculation, that contact pressure is distributed equally over the condylar surface, was considered to be significantly valid and reasonable, because patients with severe symptomatic TMJ were not included in the study.

The displacement parameters u, v, and θ by RBSM can also indicate the tendency for a dynamic stable direction. The X-coordinate component u of the displacement vector was the highest positive value in the Class III group and the lowest negative value in the Class II group. This means that the stable mandibular position in Class II cases was in a more posterior direction and that in the Class III cases was in a more anterior direction along the X-coordinate. Incesu et al. concluded that posterior condyle position could indicate anterior disc displacement (28). The tendency for posterior displacement of the condyle may promote a more anterior disc position, especially in the Class II cases. In the Class II group, the rotation value θ was negative and in the Class III group was positive. This suggests that a stable mandibular rotation direction in the Class II cases was clockwise and that in the Class III cases it was counter-clockwise. This relationship also may encourage an anterior open bite and anterior disc displacement. On the other hand, there was no significant difference between the groups in the Y-coordinate component v of the displacement vector. This suggested that the vertical position of the mandible was stable in all groups, I, II and III, which would be expected because the dental occlusion provide a vertical stop.

Conclusion

This study suggested that differences in skeletal pattern induce differences in stress distribution on the TMJ; the anatomical morphology of TMJ was also associated with stress direction and distribution on the condyle. Furthermore, the parameters such as the displacement vector (**u, v**), and the rotational angle (θ) can be useful to determine the most suitable condylar position.

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Legends

Table 1. Results of the cephalometric analysis. * : $P<0.05$.

Figure 1. Lateral cephalometric measurements used for assessment of the mandible.

Figure 2. Data collected from the lateral cephalograms. (A) The distal portion of the first molar, the gonial angle, and the condylar surface in the articular fossa were traced and the data were entered into the computer program.

(B) The gonial angle was selected as the reference point for the variables of the three degrees of freedom: parallel displacement (u, v) and rotation (θ)(counterclockwise direction is positive value). The reaction force on the teeth is assumed to act on the molars, especially on the first molar, so the distal portion of the first molar was selected as the occlusal stress generation point. The integral points for calculating the contact stress were determined along the condylar contour.

Figure 3. Visualization of the results of analysis with the rigid-body spring model. Ah: direction of resultant force vector, Ph: degree of resultant force vector, Pm: muscular power. Arrows on the condylar surface indicate relative stress on the integral points. U, V, and Angle represent the displacement vector (u, v) and (θ).

Figure 4. Statistical analysis of the resultant force vector. The value of the resultant force vector in the Class II group is significantly smaller than that in the Class I group. * : $P<0.05$. The column presents the average and the error bar shows the standard deviation.

Figure 5. Statistical analysis of the direction on the condyle. The direction

of the resultant force vector in the Class II group is significantly more anterior than that in the Class I group and that in the Class I group is significantly more anterior than that in the Class III group. * : $P<0.05$. The column presents the average and the error bar shows the standard deviation.

Figure6. Statistical analysis of the displacement vector. Significant differences are recognized between all groups in the X-coordinate component u of the displacement and the rotation angle θ. * : $P<0.05$. The column presents the average and the error bar shows the standard deviation.

Figure 7. Schematic drawings of the stress direction on the condyle in Class I, II and III patients.

		Age	SNA (dg)	SNB (dg)	ANB (dg)	Occlusal Plane - SN (dg)	Go-Gn - SN (dg)	Mandibular Plane (dg)	Mandibular Length (mm)
Class II	AVERAGE	18.9	82.6	77.1	5.6	18.8	30.4	25.2	112.0
	S.D.	7.1	4.8	4.1	2.6	5.5	7.3	6.8	8.5
Class I	AVERAGE	24.2	83.7	79.2	4.5	19.3	36.2	32.4	128.8
	S.D.	1.7	4.2	3.4	2.6	6.4	5.1	6.1	8.1
Class III	AVERAGE	22.1	81.4	84.3	-2.8	18.0	36.9	32.3	134.8
	S.D.	5.9	4.2	4.0	3.1	6.4	6.1	5.9	7.4

Table 1.

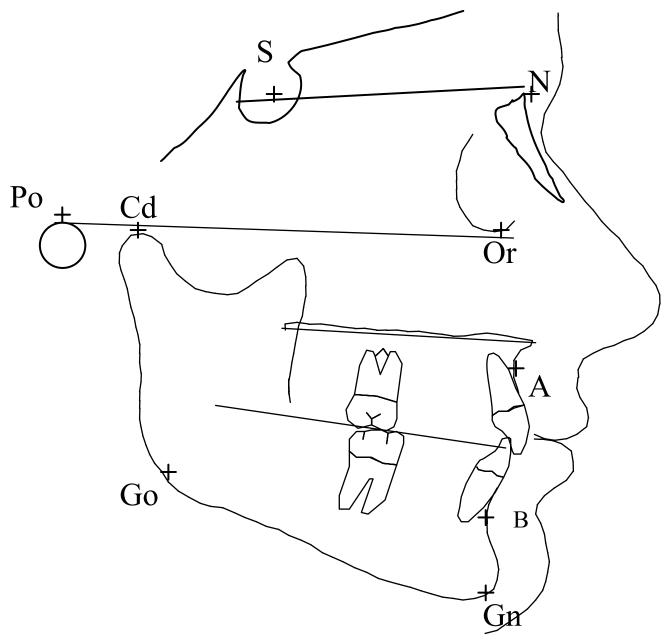


FIGURE 1.

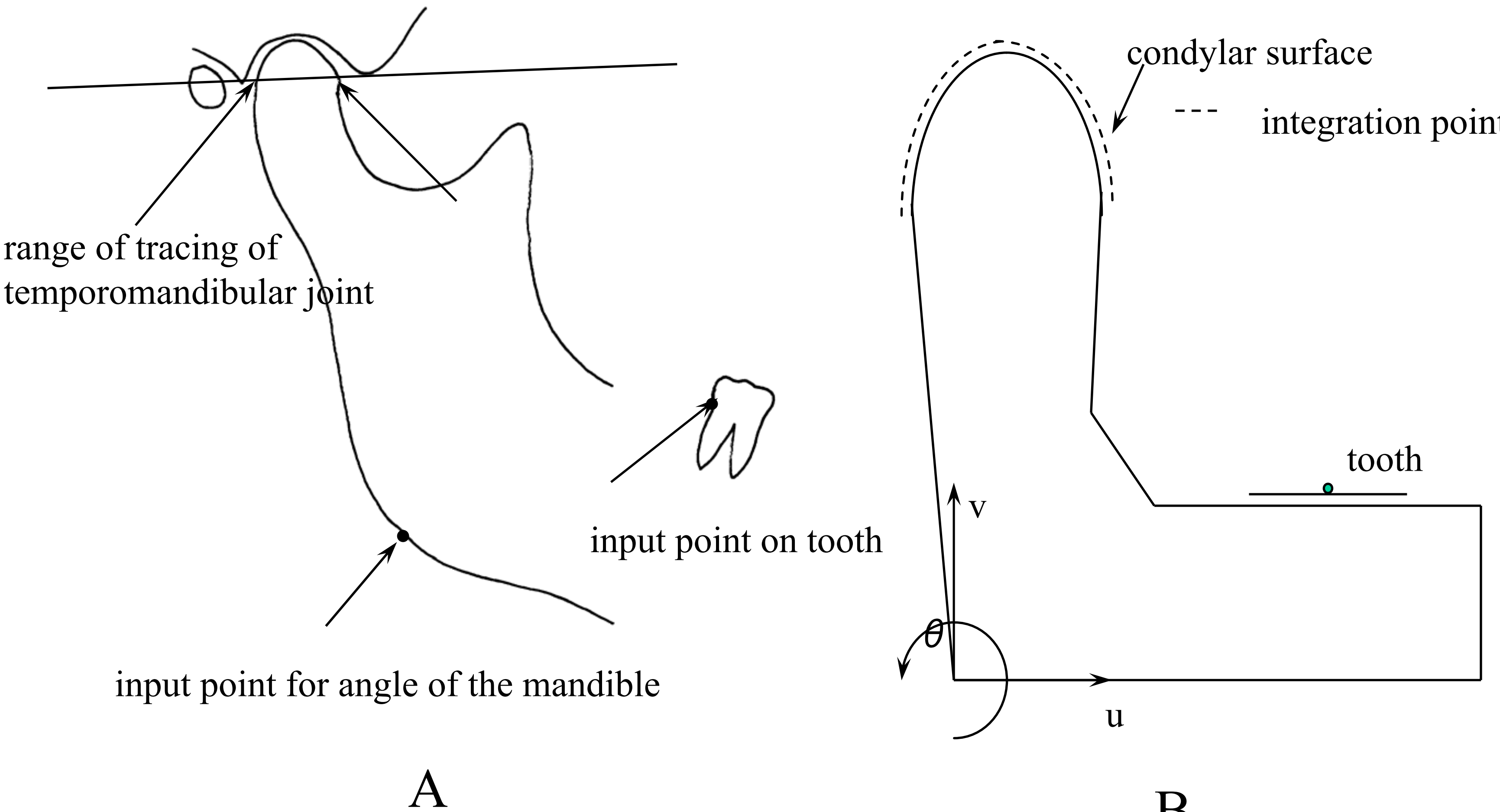
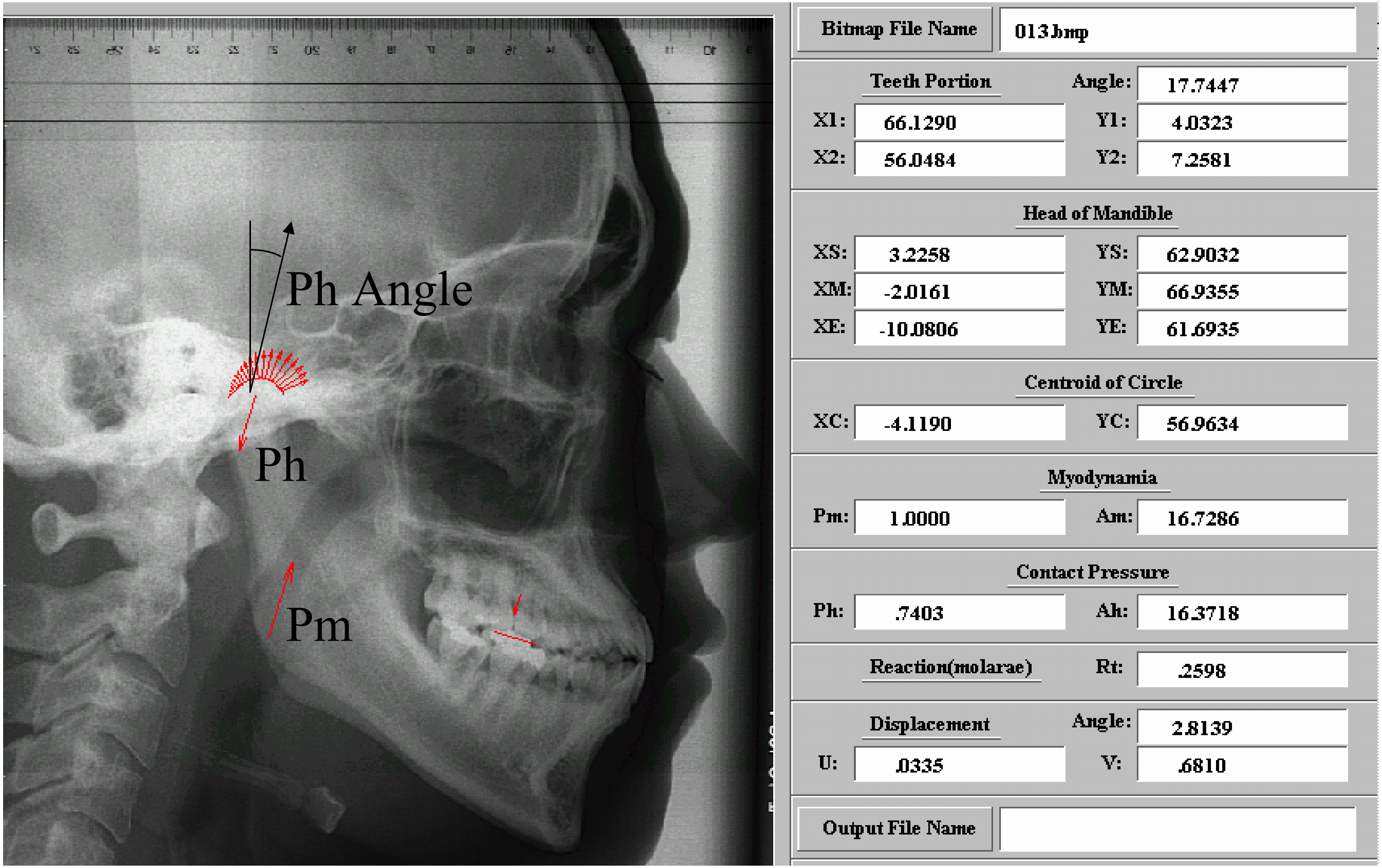

range of tracing of
temporomandibular joint
input point on tooth
input point for angle of the mandible
A
condylar surface
integration point
tooth
v
u
θ
B

FIGURE 2.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Ph
Pm
Bitmap File Name
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Y1: 4.0323
X2: 56.0484
Y2: 7.2581
Head of Mandible
XS: 3.2258
YS: 62.9032
XM: -2.0161
YM: 66.9355
XE: -10.0806
YE: 61.6935
Centroid of Circle
XC: -4.1190
YC: 56.9634
Myodynamia
Pm: 1.0000
Am: 16.7286
Contact Pressure
Ph: .7403
Ah: 16.3718
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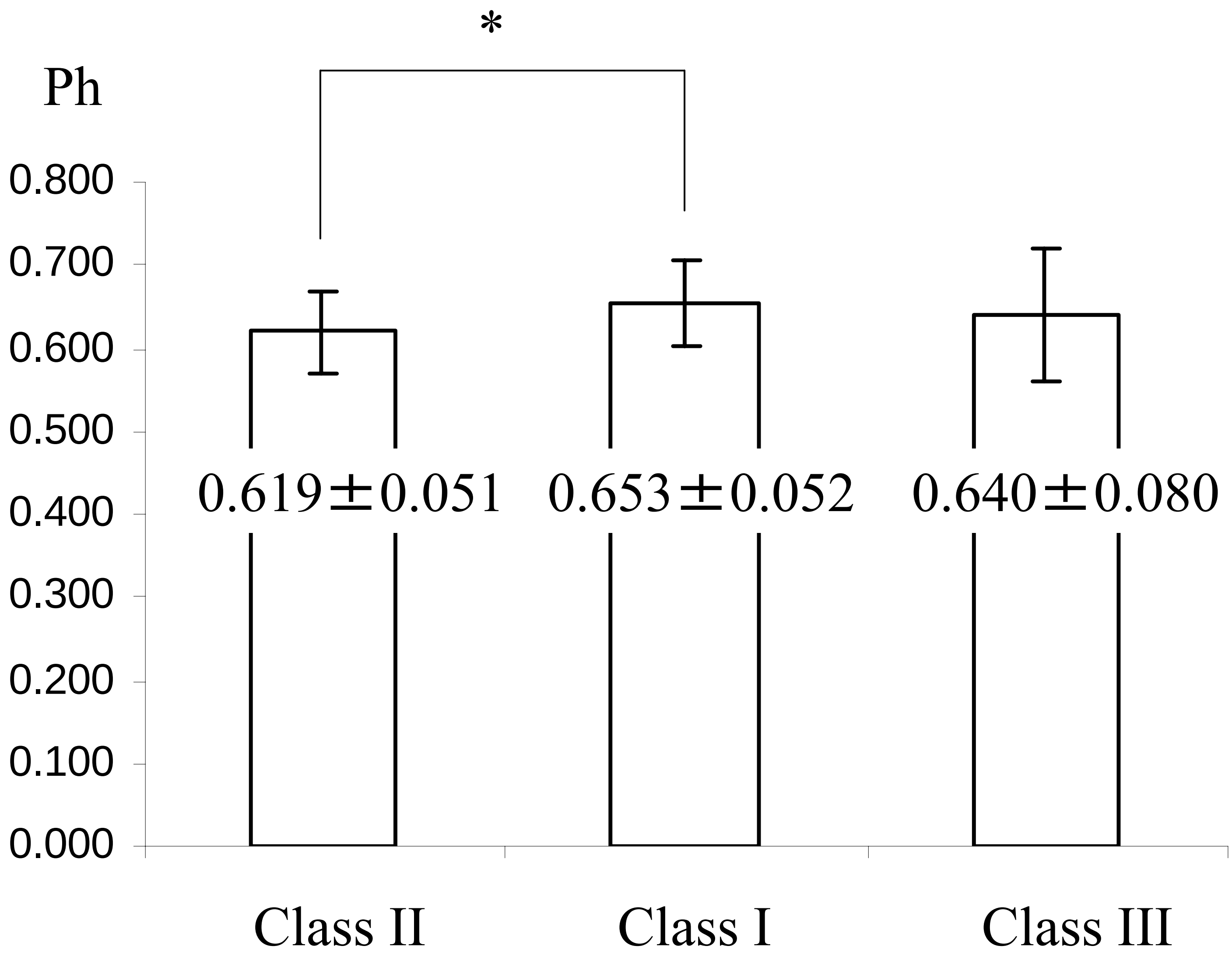
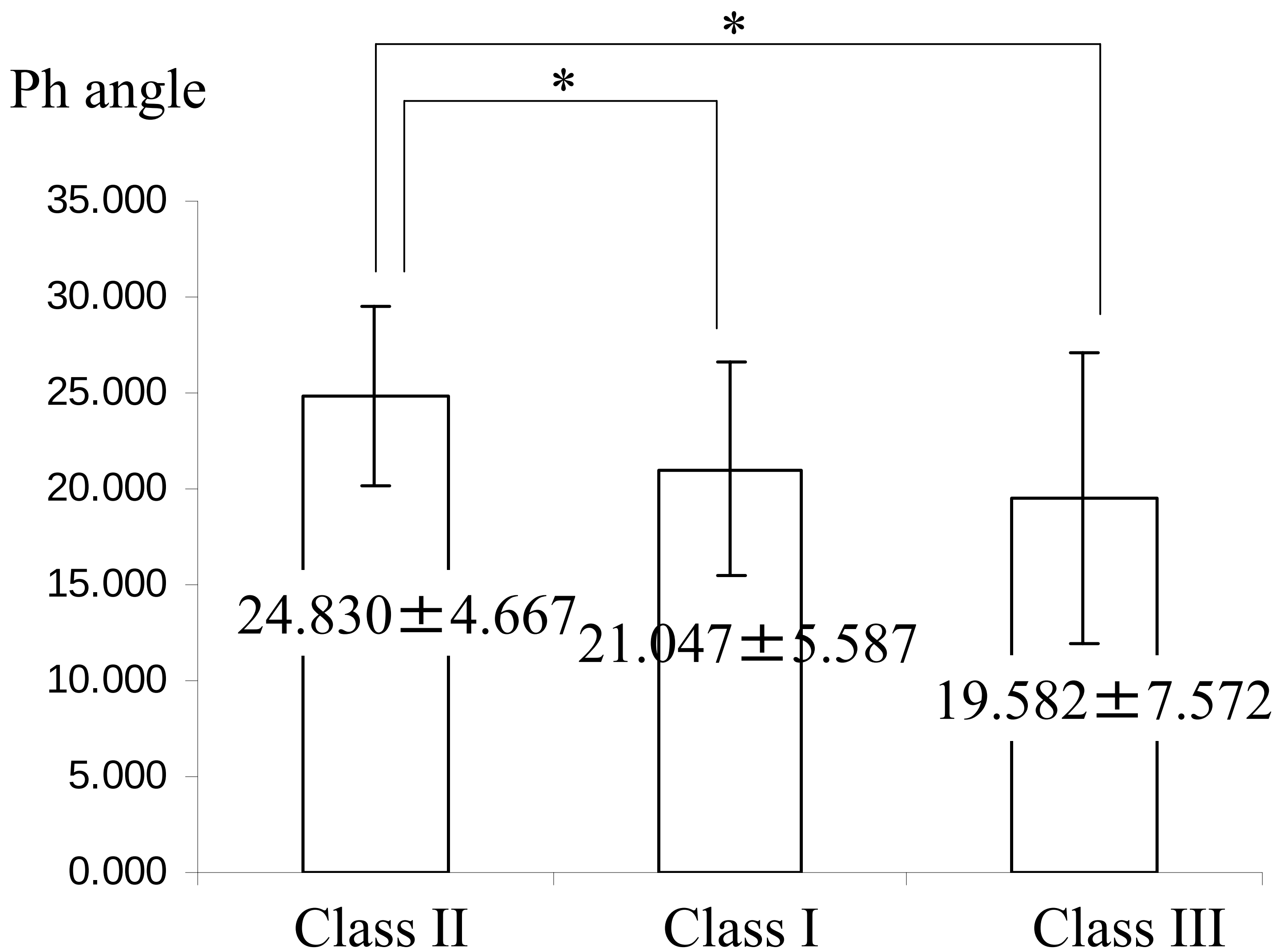
Rt: .2598
Displacement
Angle: 2.8139
U: .0335
V: .6810
Output File Name

FIGURE 3.



*
Ph
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.619±0.051
0.653±0.052
0.640±0.080
Class II
Class I
Class III

FIGURE 4.



*
Ph angle
*
35.000
30.000
25.000
20.000
15.000
10.000
5.000
0.000
24.830±4.667
21.047±5.587
19.582±7.572
Class II
Class I
Class III

FIGURE 5.

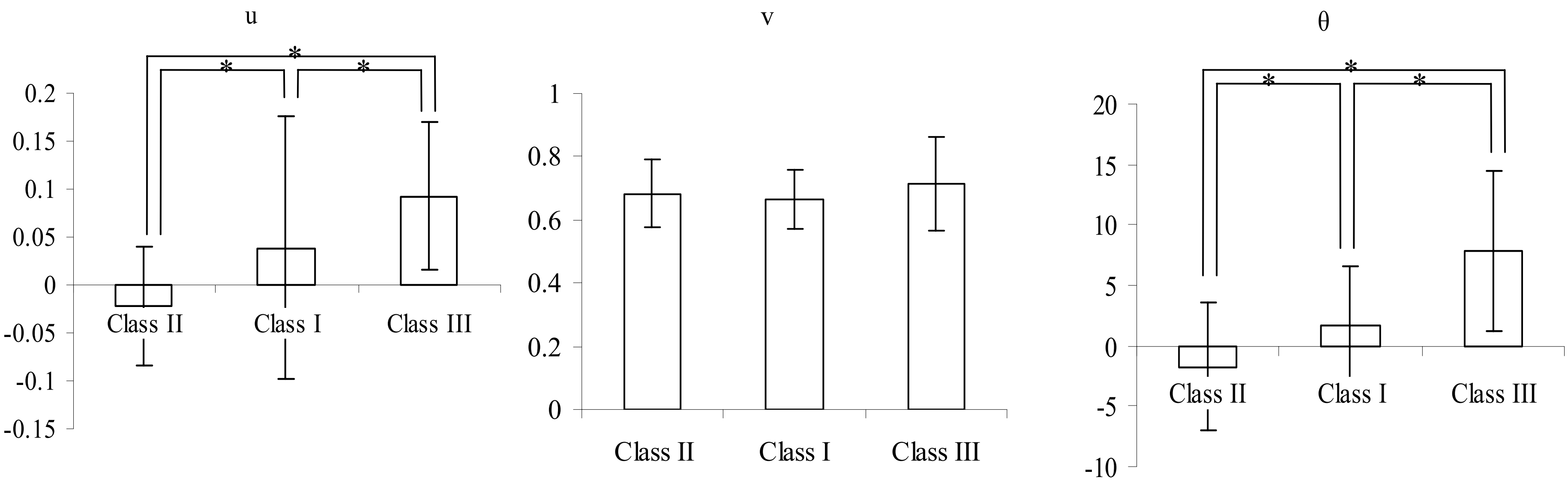
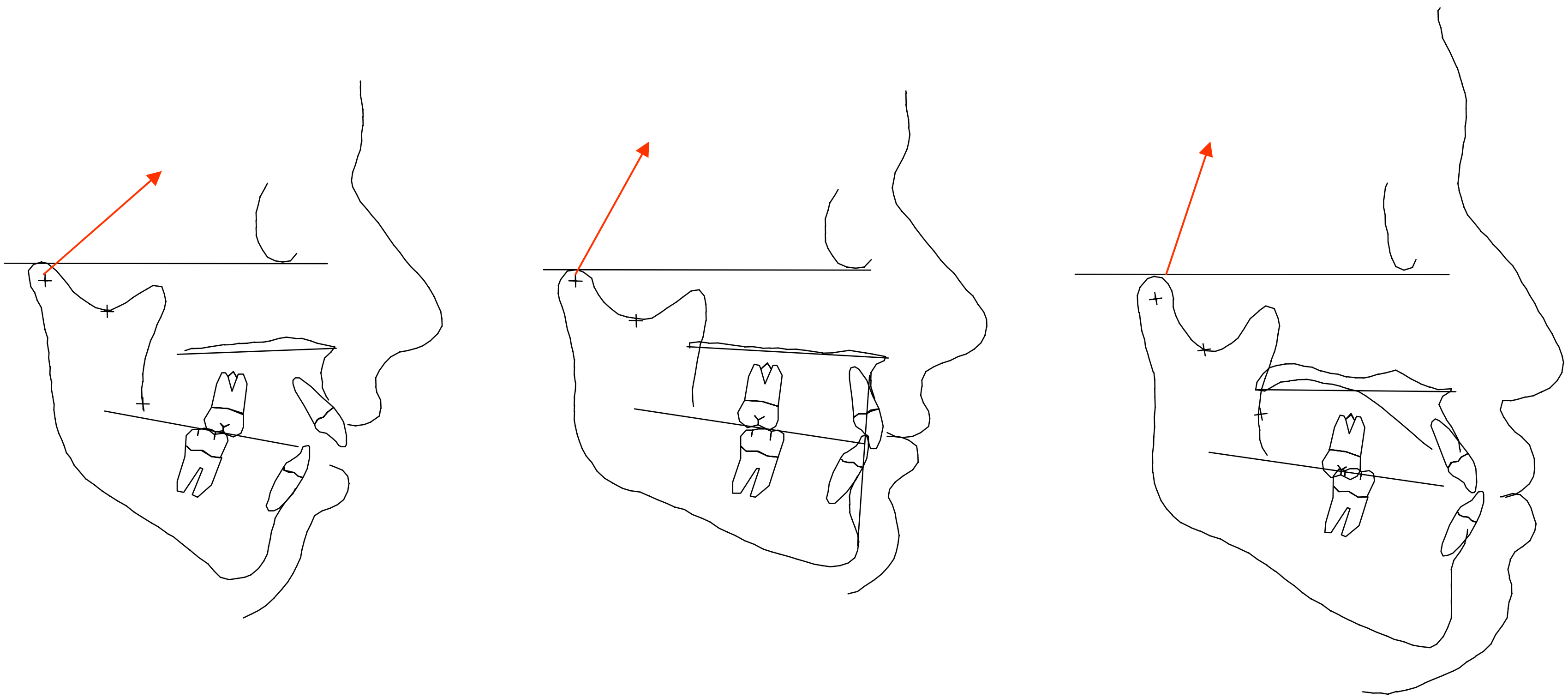

u
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
*
*
*
Class II
Class I
Class III
v
1
0.8
0.6
0.4
0.2
0
Class II
Class I
Class III
θ
20
15
10
5
0
-5
-10
*
*
*
Class II
Class I
Class III

FIGURE 6.



Class II

Class I

Class III

FIGURE 7.