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Condylar Displacement on Closure as a Risk Indicator for Internal Derangement of the Temporomandibular Joint

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Thesis submitted by Dr. Steve Chang

Abstract

Aim: The objective of this study was to determine whether direction and magnitude of condylar displacement on closure may be risk indicators for internal derangements of the temporomandibular joint.

Introduction: Occlusion's role in internal derangements of the temporomandibular joint (TMJ) disorders is still a highly debated topic in dentistry despite the anatomical association between the dentition and condylar position. The role of joint loading beyond the adaptive capacity of the temporomandibular joint complex and the pathogenesis of temporomandibular joint disorders is beginning to gain traction in the literature. The terminal stop of the joint and invariably the stresses placed on the joint are determined by the dentition at maximum intercuspation. Therefore the association between dental occlusion and temporomandibular joint disorders may just be the role of the dentition in preventing excessive load on the temporomandibular joint. Disharmony between the arc of closure of the mandible and the final seated position of the dentition may signify an incongruence of the condylar position which may have deleterious effects on the TMJ and its disc.

Methods: Eighty three patients (166 temporomandibular joints) were given a diagnosis for the presence or absence of internal derangement of each temporomandibular joint using the Research Diagnostic Criteria for Temporomandibular Disorders (RCD/TMD). Two mandibular positions were registered for each patient, maximum intercuspal position (MIP) and a neuromuscularly deprogrammed/occlusal first contact position. Using a Panadent® CPI – III Condylar Position Indicator the condylar displacement between MIP and the first contact position was determined in three dimensions. Generalized estimating equations (GEE) were used in the analysis.

Results: The association between the superior direction of condylar displacement and the internal derangement of the TMJ was positive and statistically significant (p=0.0425). This association remained positive and significant when adjusting for magnitude (p=0.0499). However, no significant association was found between the magnitude of condylar displacement in the superior-inferior plane and internal derangement of the TMJ (p=0.7803). When adjusting for superior-inferior direction there remained no significant association (p=0.7471).

A positive and statistically significant association was found between the magnitude of condylar displacement in the medial-lateral dimension and internal derangement of the TMJ, adjusting for medial-lateral direction (p=0.0285). However, condylar displacement in the medial-lateral direction showed no significant association when assessing only the magnitude (p=0.0564) of displacement. Similarly, when assessing only the direction of displacement, no association was found (p=1.0000). Furthermore, when adjusting for magnitude, the direction of displacement in the medial-lateral direction remained insignificant (p=1.0000). All other associations were not statistically significant (p>0.05)

Conclusion: Superior condylar displacement may be associated with internal derangement of the temporomandibular joint. The magnitude of condylar displacement in the medial-lateral direction may also be associated with internal derangement of the temporomandibular joint. No significant associations were found between internal

derangement and the direction and magnitude of condylar displacement in the anterior-posterior direction.

The association found in this study between condylar displacement and internal derangement of the temporomandibular joint, albeit inconsistently, may be indication of an orthopedically unstable occlusion leading to an orthopedically unstable condylar position. This orthopedically unstable joint complex may increase the risk for internal derangement of the temporomandibular joint. Therefore, measuring condylar displacement may represent a new dogma on measuring occlusion and its effects at the condylar level which may give further insight on the effect of condylar position on TMD.

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Introduction

Internal Derangement (Disc Displacement) of the Temporomandibular Joint

The temporomandibular joint (TMJ) is considered a unique joint of the human body. The TMJ is the area in which the mandible articulates with the cranium and has a vital role in mastication and deglutination. It allows for both hinging movements (ginglymoid joint) and also gliding movements (arthrodial joint) and is therefore considered a ginglymoarthrodial joint. Functionally, the condylar head of the mandible articulates with the mandibular fossa of the temporal bone at the base of the skull. These two bony structures are separated by an articular disc which allows for the dynamic movement of this unique joint. [1]

The articular disc is a dense piece of fibrous connective tissue that is for the most part avascular and aneural. Its function is to allow the relative movement of the bony structures which it separates. The shape of the disc is dictated by the morphology of the condyle and the mandibular fossa. The disc does, however, become thicker at both borders anteriorly-posteriorly and medially-laterally with the disc being thickest, medially and posteriorly. [1]

The TMJ is an extremely complex joint system from its anatomy to its function. Its structure and function can be divided into two distinct systems: condyle-disc relationship and disc-fossa relationship. The articular disc allows the concave mandibular fossa and the convex condylar head to function harmoniously. It has been suggested that the ideal anatomical position of the disc is on top of the anterior superior portion of the condyle with its thinnest central part between the condyle and the posterior slope of the eminence when the mouth is closed.[1] However, the ideal condylar position has been greatly debated for some time without a consensus agreement.[2-6]

A disc displacement (DD) is a change in the disc-condyle relationship of the temporomandibular joint system. These disc displacements have been classified into two categories: disc displacement with reduction and disc displacement without reduction.

Disc displacement with reduction occurs when, at full mouth closure, the disc is no longer positioned ideally over the condylar head and is only recaptured during movements of the mandible. Patients with DD with reduction typically will produce a clicking noise during mandibular movements.

Disc displacement without reduction occurs when, at close, the disc is no longer positioned ideally over the condylar head and does not recapture the condyle-disc relationship throughout movements of the mandible.

Etiology of Disc Displacements

The etiology of disc displacements has remained a highly debated topic. Under normal function, as muscle activity increases, the condyle is increasingly forced against the disc and the disc against the fossa. This leads to an increase in the interarticular pressure within the joint structure. When the pressure is low, as in the rest position, the disc space widens. When the pressure is high, for example during clenching of the teeth, the disc space narrows.[7] It is theorized that a biomechanical load beyond the physiologic capacity of the TMJ causes the chronic fatigue of the disc leading to deformation and displacement of the disc. During mandibular movements the disc is to some extent flexible and can adapt to the functional demands placed on it by the articular surfaces.

Therefore, the shape of the disc is reversibly changed during function; however, the disc maintains its morphology unless forces beyond the physiologic capacity of the joint occur. [8] If these changes to the articular disc occur, it is has been suggested that the morphology of the disc can be permanently changed, causing functional and sometimes deleterious changes during function. [8, 9] Tanaka *et al*. state that the mechanical stresses applied to the temporomandibular joint may likely be the contributing and causative factor to internal derangements of the TMJ. Furthermore, excessive compressive and shear stresses, especially, are probably the most common sources of condylar resorption. [10, 11]

Recent studies using three-dimensional finite element model analyses have shown that compressive strain produced during a static period of loading of the TMJ is likely to significantly increase tissue stresses and increase the risk of mechanical fatigue of the TMJ. [12, 13] With constant articular surface breakdown there may be an increase in friction between the articular surfaces and the articular disc. This friction leads to reduced disc movement during joint function and stretching of discal ligaments. This may cause an irreversible stretching of the ligaments and increase the potential for disc displacement and possible perforation of the disc complex. [14]

A study by Katzberg *et al.*, using magnetic resonance imaging of the articular disc and the posterior disc attachment of the disc, showed significant differences between patients with symptomatic and asymptomatic temporomandibular joints. They found symptomatic patients to have a greater number of internal derangements compared to that of patients with no temporomandibular joint symptoms. Deformity of the disc was noted in 34 of 116 (29.3%) of joints in patients with TMJ symptoms and only 5 of 122 (4%) of joints of asymptomatic patients (P < 0.0005). The authors also found that disc deformation was more prevalent with a greater degree of displacement such as that with disc displacement without reduction. [15]This study, however, did not distinguish between TMD symptomatic patients and the type of TMD pain they were experiencing. Further elucidation on the characteristics of TMD pain may shed more light on the role of the articular disc in TMD related pain. This study corresponds with previous cadaver and histological studies that show morphologic changes in shape and composition of the articular disc as well as tears and perforations of the posterior attachment assembly. [16-18]

However, the difficulty with these studies is that there is no measure of what physiological capacity is. The results are either retrospective in nature or *in vitro* studies. If biomechanical loads are in fact the cause of disc displacements then there must be some measure beyond which the articular disc can no longer handle normal physiological load.

Condylar Position

In order to understand whether an abnormal occlusion mediates an abnormal condylar position leading to TMJ pathology, one must understand where the normal position should be. Ideal condylar position, however, has been debated endlessly and has yet to be resolved. Therefore at this time an "ideal condylar position" is variably defined based on the concepts one follows. However, since the TMJ is a load bearing joint, it may stand to reason, that an optimal position where the fossa, disc and condyle can withstand these stresses would be ideal. Studies have shown that the normal forces applied to the disc by the condyle during maximum intercuspation were directed perpendicular to the posterior slope of the articular eminence. It was shown that when the force angle to the eminence was acute, the condyle was subject to a translational force that displaced the disc. [19, 20] This may be evidence that deviation from an "ideal condylar position" may place the joint in an unfavorable position to handle loading of the joint leading to possible deleterious effects.

Centric Relation (CR) has represented an ideal condylar position for many years in dentistry; however, there is little agreement on its definition. Williamson describes centric relation as "a position of the condyles in their respective fossa, where the condyles are centered and in a most superior posterior position, with the discs interposed on the posterior inclines of the articular eminentia". [21] This position is in vast contrast to CR as defined by Dawson.

Dawson describes centric relation as a "mandibular-maxillary relationship with the condyle disc assemblies positioned most superiorly against the eminentia and the medial pole braced at the uppermost medial part of its reciprocal fossa contour, irrespective of tooth position." [22]

Jankelson describes a condylar position that does not depend on the bony structures of the TMJ as a reference. Rather, he proposes that the neuromuscular position of the condyle be one that requires "a relaxed musculature to obtain an occlusal position affecting condyle fossa relationships indirectly". [23]

At present the inconsistency of the understanding of centric relation is nowhere more evident than in the Journal of Prosthetic Dentistry and their Glossary of Prosthodontic

Terms. Here they define seven different versions of centric relation. Clearly there are inconsistencies in the dental community's understanding of centric relation. [21]

Despite these inconsistencies in the understanding of centric relation, one theory that may explain the inability of the articular disc to handle too great a load placed upon it is a condyle that is not properly situated in the TMJ complex. This may put the articular disc in an unfavorable position to handle all the stresses imposed on it by the condyle. Studies have shown that there may be a correlation between condylar position and TMD. [24-27] A study by Crawford set out to determine if there is a relationship between condylar position (as determined by dental occlusion) and signs and symptoms of TMD. Subjects with reconstructed occlusions where centric relation approximated centric occlusion were compared with a control group of patients with no treatment from the general population. Using a dental articulation system specifically designed to determine the condylar position the author found a statistically significant relationship between condylar position and symptoms of TMD. There was an 84% reduction in symptoms of TMD with a high correlation between the signs and symptoms of TMD and condylar positions further from CR ($p < 0.001$). The author argued that occlusion is seen as the determining factor in the condylar position in maximum intercuspation. [28] There have been several studies that have used dental articulating systems to record condylar positions in both CR and MIP positions. [26, 28-30] Crawford performed a pilot study to determine the accuracy and the reliability of the CPI instrument and technique. The author found no statistically significant differences in either intra- or inter-operator studies when subjected to a two-tailed *t*-test set at a 99% confidence level. Intra-operator results were consistent with a variance equal to 0.023mm. [28]

Another study by Gateno *et al.* in 2004 found that condyles of patients with anterior disc displacements were situated more posteriorly and superiorly in the fossa than those in a control group of patients that did not have disc displacements. They also found the posterior condylar displacement to be 2.4 times greater than the superior condylar displacement in these patients. [31] Based on the aforementioned studies it could be hypothesized that the magnitude of condylar distraction by the occlusion from the centric relation (CR) position is related to TMD symptomatology.

Kinniburgh *et al.* set out to determine differences in spatial relationships and osseous morphology between temporomandibular joints with normal and anterior disc positions. Using magnetic resonance imaging it was determined that there was a significant difference for all measures of joint space, condylar position between joints with normal disc position (no disc displacement) and with full anterior disc displacement. They found that the anterior disc position results in increased anterior joint space and a reduced superior and posterior joint space. [32, 33] This study coincides with the studies by Crawford and Gateno that radiographically there are differences in condylar positions between symptomatic and asymptomatic patients. Further study is required to delineate which TMD diagnoses are more relevant to condylar position, if they are relevant at all. If condylar position is in fact an important consideration to the health of a temporomandibular joint, the change in this position would be of importance.

Occlusion and the Temporomandibular Joint

The role of occlusal factors on the etiology of temporomandibular disorders including disc displacements has long been a source of great debate and controversy in the field of dentistry. [34-36] Some in the field believe that malocclusion has a distinct role despite the highly inconsistent findings with respect to malocclusion as an etiology of TMD. [37-40] Conversely, there is an abundance of literature that shows occlusion having only a minor role in TMD or no role at all. [41-45] Despite the lack of scientific evidence linking malocclusion to TMD etiology, clinicians continue to treat certain types of malocclusions which have proven to be effective and predictable in the management of some temporomandibular disorders. [30, 46-48]

The anatomical associations between the dentition and the temporomandibular joints have led to several studies that have attempted to define their relationship with each other. Studies have related the dentition to the TMJs by measuring the relationship of the maxillary dentition to the mandibular dentition with the assumption that any dental deviation could represent a deviation in the TMJs. [49-51] However, tooth to tooth relationships may be poor indicators of condylar position. [52] For example, concomitant dental midlines may not correspond to facial midlines. Also, overbites on worn dentitions would not be an accurate measure of vertical collapse. Studies have shown that the dental midline is situated in the exact middle of the mouth in only approximately 70% of people and that the maxillary and mandibular midlines fail to coincide in almost three fourths of the population. [53] It has also been shown that there are no significant differences in condylar position between Class I and Class II groups based on ANB or Angle's classification. [54] A Class II malocclusion may result from a maxillary overgrowth, poor mandibular development, retroclined mandibular teeth, proclined maxillary teeth, a distalized condylar position, or any combination of these factors. It could also be argued that these same occlusal measurements, if measured one dimensionally and using unreliable landmarks as points of measure, may not equate to condylar position as it relates to TMDs. The condyles, in fact, function in a three dimensional manner. [55, 56]

Studies by Seligman and Pullinger have tried to find an association between occlusal variables such as dental attrition, over-bite and over-jet to predict intracapsular temporomandibular disorders. These factors showed little to no association to internal derangement of the temporomandibular joint. [57-60] However, their studies examining the anatomic relationships of the condyle proved more predictable in their association with internal derangements of the joint. They stress that the temporomandibular joint and associated disease processes are multifactorial and single explanations of these disorders should be avoided. [61-63]

Even though occlusion dictates the final condylar position observation of occlusion alone does not seem to reveal what happens at the condylar level. It would stand to reason that a different occlusion based examination is required. This measure would need to give the clinician some indication regarding the manner in which the occlusion affects the condylar position.

Condylar Displacement

Traditionally, occlusion has been viewed from a static tooth-to-tooth relationship. As previously stated, this measure gives no indication to the effect that the dentition has at the condylar level. Clinicians, however, continue to use tooth-to-tooth relationships to predict TMJ dysfunction. [64] Nevertheless, there is little debate that the final condylar position is dictated by the maxillomandibular relationship. The dentition acts as a guide and a terminal stop for the condylar position relative to the fossa. Therefore, it has been proposed that occlusion needs to be viewed from a different perspective that allows for the interpretation of the effect of occlusion at the condylar level. This would require a change in the static measure of occlusion. The difficulty of measuring occlusion other than a static position has been shown by Lerman *et al*. They state that hiding the masticatory muscles' reaction (the mandibular shift) limits the success of achieving occlusion-muscle compatibility. They found that masticatory muscles have "muscle memory"; the engram may hide the nature of the closing stroke of the mandible. Whenever the mandible is guided into MIP the muscles of mastication would rely on the phenomenon of muscle memory to more accurately guide the mandible in the maxilla. This would make a neuromuscularly relaxed position/condylar hinge axis rotation difficult to be distinguished from MIP. However, Lerman *et al.* determined that the muscle conditioning by dental occlusion would last less than two minutes. [65]

If not a static assessment of occlusion, a dynamic understanding of occlusion stands to reason. It is the musculature of the TMJ complex that provides the forces to allow the mandible to close into MIP. From an isotonic muscle position at rest it is said to allow the mandible to function around its condylar hinge axis. [22] Therefore, it has been proposed that a neuromuscularly relaxed position should place the condyles in the ideal position on closure irrespective of the dentition. However, several investigations have shown that in a large population of cases maximum intercuspal position was not compatible with neuromuscular relaxation and that the occlusion showed some deviation in multiple dimensions from the neuromuscular position. This would represent a centric occlusion to maximum intercuspal position discrepancy; a mandibular shift on closure. Futhermore, they hypothesized that this discrepancy may indeed have some correlation to temporomandibular joint dysfunction. [29, 66, 67] Several studies have now attempted to show that this occlusion mediated mandibular shift is related to temporomandibular joint dysfunction. [26, 29, 68] He *et al*. found that a positive CR-MI discrepancy, defined as a discrepancy exceeding 1mm in the vertical or horizontal planes or 0.5 mm in the transverse plane, was found in 72.9% of their experimental group (patients with signs and symptoms of TMD defined by the RDC/TMD) and 11.4% in their control group ($P < 0.001$). Further evaluation also found that a CR-MI discrepancy was significantly correlated with anamnestic dysfunction and clinical dysfunction of the TMJ. [27]

Joint Loading

Like other synovial joints the temporomandibular joint is under load during function. The articular surface of the condyle is covered in cartilage that plays an important role in stress compensation during mechanical load. Furthermore, the cartilaginous surfaces interact between an articular cartilaginous disc within a joint cavity where the spaces between these surfaces are filled with synovial fluid. This complex joint is designed to withstand friction and load through these mechanisms.

If indeed the dentition has a role in protecting the joint from excessive loading it would be expected that there would be a deleterious effect on the condyle if there was failure in the masticatory system. A finite element study by del Palomar *et al.* showed that during clenching, there was an even distribution of force along the maxillary arch which prevents the TMJ from overloading. In contrast, patients with severe partial edentulism seem to induce overloading of the TMJ. [69] Furthermore, Uma *et al.* found that the mandible undergoes significant changes in response to complete edentulism in both position and morphology. [70]

A study by Wu *et al.* showed that excessive mechanical loading of the temporomandibular joint in a rat model caused an increase of intra-articular pressure leading to an inflammatory response such as production of cytokines, matrix-degrading enzymes and pro-inflammatory factors. They concluded that joint loading caused these inflammatory reactions that are instrumental in the arthritic changes in the joint. [71]

Kuroda states that in an overloaded joint there is increased intra-articular pressure. This may exceed the capillary perfusion pressure needed by the avascular fibrocartilage of the joint's articulating surfaces. This may cause the degradation of the cartilage. He stresses that the TMJ, while different in certain anatomical features from other joints, undergoes similar disease processes as other load bearing joints. [72]

These types of stresses may explain the changes in disc shape found in some patients with internally deranged joints. Taskaya-Yylmaz *et al.* found that the more deformed the articular disc shown via MRI the more the degree of internal derangement. [73]

An MRI study by Hopfgartner *et al.* found that a joint under physiologic load in terminal occlusion showed a decrease in space between the head of the condyle and the fossa. [74]

While the physiological load on the TMJ complex is created by the muscles of mastication, it is the dentition that is load limiting as it controls the final position of the condyle. Excessive load on the joint is only possible if the dentition allows. Condylar position has been thought to have a role in internal derangement of the joint due to both anatomical malposition and joint loading. Gateno *et al.* found that patients with anterior disc displacements had condyles more posteriorly and superiorly positioned in the fossa and that the joint space between the fossa and condyle was less. As the joint space decreases between the fossa and the condyle the disc may have increasing load placed upon it. [31]

Summary

An association between disc displacements of the temporomandibular joint and forces beyond physiologic capacity of the disc has been reported in the literature. [7-9] It would be reasonable to postulate that if the condyles are not properly situated, the disc to condyle relationship may not be properly aligned which may not allow the disc to withstand the forces applied to it. This condylar position, being an occlusion determined position, may lead to the conclusion that occlusion and disc displacements are related and that occlusal measures should be predictive of disc displacements. However, as previously stated, traditional occlusal measures like Angle's Classification, overbite and overjet are not relevant to condylar position. Therefore, a new measure of occlusion is required to understand the effect at the condylar level. Hence, measuring a mandibular shift may represent a new dogma on measuring occlusion and its effects at the condylar level which may give further insight on the effect of condylar position on TMD.

Specific Aims and Hypothesis

The primary aim of this study was to examine the association between condylar displacements on closure and internal derangements of the temporomandibular joint. Based on the review of literature, we hypothesized a positive association between the magnitude of dentally mediated change (displacement) of condylar position and internal derangement of the temporomandibular joint. More specifically we hypothesized that the superior, posterior and medial direction of condylar displacement would be positively associated with internal derangement of the temporomandibular joint due to stresses placed on the disc and associated structures interposed between the cranium and the condyle.

Research Design and Methods

This study was approved by the Western Institutional Review Board under the study number 1136373, January 8th, 2013.

Methods

To test the proposed hypotheses patients were identified with and without internal derangements of the TMJ as defined by the Research Diagnostic Criteria for Temporomandibular Disorders. [75] The magnitude of condylar displacement from the first tooth contact position during the closing stroke to maximum intercuspation (MIP) was then assessed in these patients. Condylar positions were assessed using a dental articulator specifically designed to determine occlusion determined condylar positions. This mandibular shift should signify a maxillomandibular relationship mediated change in condylar position.

Eighty three patients (166 temporomandibular joints) attending a single general dentistry practice in Barrie Ontario, Canada were used for this study.

Exclusion Criteria

All volunteer subjects satisfying the following exclusionary criteria were excluded from this study:

- Subjects with an unrepeatable Maximum Intercuspal Position (MIP)

- Subjects under the age of 18
- Subjects currently undergoing bite appliance therapy for Temporomandibular Joint Disease (TMD)
- Subjects currently undergoing orthodontic treatment
- Subjects with a history of TMJ/Orthognathic surgery
- Subjects who have had injuries to the temporomandibular joint within 6 months

All subjects available to this study were given basic dental examinations prior to involvement in this study. This included a dental, radiographic, oral and periodontal examination. Upon completion of the appropriate consent documentation each subject was given an identification number in order to properly blind the examiners.

TMD Diagnosis using the Research Diagnostic Criteria for Temporomandibular Disorders

All diagnoses of internal derangement or lack thereof were made using the protocols set forth by the RDC/TMJ by a licensed dentist. Each subject had both joints assessed. The Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) has allowed researchers the standardization and replication of research. The RDC/TMD allows for a reliable diagnostic classification system that has been shown to be reproducible among clinicians and researchers and was therefore used in this study to identify the patient's TMD status. This study identified patients following the protocols set forth by the RDC/TMD. [75-78] Each patient was accordingly given an appropriate diagnosis for internal derangement of each temporomandibular joint.

The following RDC/TMD forms were used in this study:

- History Questionnaire of the RDC/TMD
- Clinical Examination
- Axis I Diagnostic Algorithms (Figure 1)

Mandibular Positions

For the purposes of this study, two mandibular positions were registered for each patient. The first position is maximum intercuspal position (MIP). This is a relationship in which there is a complete intercuspation of the opposing dental arches, independent of the condylar position. The second position determined was a neuromuscularly deprogrammed occlusal/first contact position. (APPENDIX C) It has been shown that a five minute chair-side neuromuscular deprogramming with separation of the dentition (accomplished by placing a cotton roll between the anterior teeth) was effective to establish a condylar position without the influence of the dentition and muscular engrams. [29, 65]

In this study the Panadent Condylar Position Indicator system was used following the manufacturer's protocol to determine the condylar positions (APPENDIX D).

After diagnostic impressions were taken of both the maxillary and mandibular arches using an alginate impressioning material (Jeltrate® Plus™) stone models (Whipmix Microstone) were fabricated. These were subsequently mounted onto a Panadent® CPI – III Condylar Position Indicator articulator (Figures 2, 8).

The Panadent CPI – III Condylar Position Indicator Articulator with the mounted casts for each subject was assessed and identified in the following bite positions following the manufacturer's protocol.

1. Maximum intercuspal position (Figure 3)
2. First point of contact/Deprogrammed position (Figure4)

The bite registrations were used to position the mandibular model to the maxillary model on the articulator in order to calculate the relative condylar position for each bite position.

The following measurements were obtained using the Panadent CPI – III Condylar Position Indicator:

1. Panadent CPI – III Right Joint Vertical Graph (mm) (Figures 5,9)
2. Panadent CPI – III Left Joint Vertical Graph (mm) (Figures 5,9)
3. Panadent CPI – III Transverse Graph (mm) (Figures 6,9)

The aforementioned graphs measured the anterior-posterior (A-P), superior-inferior (S-I), medial-lateral (M-L) condylar position change between each bite registration (for each joint). The graphs were measured using a digital caliper.

Power Calculation

A power calculation was performed using nQuery Advisor (Version 7.0). Assuming an odds ratio of 2.5, a sample size of n = 82 subjects was adequate to obtain a Type I error rate of 5% and a power of 80%. This study was approved by the Western Institutional Review Board for the collection of 82-100 subjects.

Statistical Analysis

Means and standard deviations were recorded for continuous variables; counts and percentages were recorded for categorical variables. The association between condylar displacement and disc displacement was assessed via generalized estimating equations (GEE). P-values less than 0.05 were considered statistically significant. SAS version 9.2 (SAS Institute, Cary, North Carolina) was used in the analysis.

Results

Two subjects were excluded from this study. One subject refused to have their assessment part of the results and a second subject had their models break during handling.

Of the 83 subjects 62 were female (75%) and 21 were male (25%) (Figure 10). Of these subjects 58 (70%) had some form of internal derangement of the temporomandibular joint with subjects with one joint with internal derangement at 27 (32.5%) and subjects with both joints with internal derangement at 31 (37.3%) (Figure 17). The average age of the subjects in this study was 38 years (SD = 12) (Figure 11). Of the 166 joints assessed 89 (54%) were diagnosed with an internal derangement (Figure 12).

Anterior-Posterior (A-P) Plane

Of the 141 joints assessed (excluding joints with no magnitude of displacement) 116 (82.3%) joints had a posterior condylar displacement. Of the posteriorly displaced condyles 62 (53.4%) were internally deranged. Conversely, 25 (17.7%) had an anterior condylar displacement. Of the anteriorly displaced condyles 11 (44.0%) were internally deranged (Figure 18). Of the 166 total joints assessed 141 joints (84.9%) moved to a neuromuscularly deprogrammed position in the anterior-posterior dimension.

Using GEE with internal derangement of the TMJ as the dependent variable and the magnitude of condylar displacement as the independent variable no significant association was found in the A-P direction (p=0.6289) (Table 1). Further assessment, adjusting for directionality of condylar displacement in the A-P plane, also revealed no significant association (p=0.3177) (Table 2).

Using GEE with internal derangement of the TMJ as the dependent variable and the direction of condylar displacement as the independent variable (excluding joints with zero magnitude n= 141 joints), no significant association was found between the A-P direction of condylar displacement and internal derangement of the joint (p=0.6527) (Table 3). Further assessment, adjusting for the magnitude of condylar displacement in the A-P plane, also revealed no significant association (p=0.8993) (Table 4.)

Subsequently, comparing joints with or without condylar displacements and internal derangement of the TMJ using GEE, no significant associations was found (p=0.1257) (Figure 14). Among the joints with no condylar displacement, 16 of 25 (64.0%) had an internal derangement. Of those joints that had a condylar displacement, 73 of 141 (51.8%) had an internal derangement (Figure 13, 14).

An odds ratio calculation for magnitude of displacement and internal derangement was 1.049 (Table 1). After adjusting for direction and excluding joints with no magnitude of displacement, the odds ratio calculation was 1.123 (Table 2).

Furthermore, an odds ratio calculation for posterior condylar displacement (with anterior as reference) and internal derangement was 1.231 (Table 3). After adjusting for magnitude, the odds ratio was 1.065 (Table 4).

Inferior-Superior (I-S) Plane

Of the 134 joints assessed (excluding joints with no magnitude of displacement) 93 (69.4%) joints had a superior condylar displacement. Of the superiorly displaced condyles 55 (59.1%) were internally deranged. Conversely, 41 (30.6%) had an inferior condylar displacement. Of the inferiorly displaced condyles 15 (36.6%) were internally deranged (Figure 19). Of the 166 total joints assessed 134 joints (80.7%) moved to a neuromuscularly deprogrammed position in the inferior-superior dimension.

Using GEE with internal derangement of the TMJ as the dependent variable and the magnitude of condylar displacement as the independent variable no significant association was found between in the I-S direction (p=0.7803) (Table 1). Further assessment, adjusting for directionality of condylar displacement in the I-S plane, also revealed no significant association (p=0.7471) (Table 2).

Using GEE with internal derangement of the TMJ as the dependent variable and the direction of condylar displacement as the independent variable (excluding joints with zero magnitude n=134 joints) a significant positive association was found between the superior direction of condylar displacement and internal derangement of the joint (p=0.0425) (Table 3). Further assessment, adjusting for the magnitude of condylar displacement in the I-S plane revealed that this association remained positive and significant (p=0.0499) (Table 4).

Subsequently, comparing joints with or without condylar displacements and internal derangement of the TMJ using GEE, no significant association was found (p=0.3090). Among the joints with no condylar displacement, 19 of 32 (59.4%) had an internal derangement. Of those joints that had a condylar displacement, 70 of 134 (52.2%) had an internal derangement (Figure 13, 15).

An odds ratio calculation for magnitude of displacement and internal derangement was 1.050 (Table 1). After adjusting for direction and excluding joints with no magnitude of displacement, the odds ratio calculation was 1.062 (Table 2).

Furthermore, an odds ratio calculation for superior condylar displacement (with inferior as reference) and internal derangement was 2.407 (Table 3). After adjusting for magnitude, the odds ratio was 2.349 (Table 4).

Medial-Lateral (M-L) Plane

Of the 112 joints assessed (excluding joints with no magnitude of displacement) 56 (50%) joints had a medial condylar displacement. It should be noted for each joint that moves medially, the contralateral joint moved equally in the lateral direction. Of the medially displaced condyles 31 (55.3%) were internally deranged. Of the laterally displaced condyles 31 (55.3%) were internally deranged (Figure 20). Of the 166 total joints assessed 112 joints (67.5%) moved to a neuromuscularly deprogrammed position in the medial-lateral dimension.

Using GEE with internal derangement of the TMJ as the dependent variable and the magnitude of condylar displacement as the independent variable no significant association was found in the M-L direction and internal derangement of the joint (p=0.0564) (Table 1). Further assessment, adjusting for directionality of condylar displacement in the M-L plane revealed that there was a significant positive association between the magnitude of condylar displacement and internal derangement of the TMJ (p=0.0285) (Table 2).

Using GEE with internal derangement of the TMJ as the dependent variable and the direction of condylar displacement as the independent variable (excluding joints with zero magnitude n = 112 joints), no significant association was found between the M-L direction of condylar displacement and internal derangement of the joint (p=1.0000)

(Table 3). Further assessment, adjusting for the magnitude of condylar displacement in the M-L plane, also revealed no significant association (p=1.0000) (Table 4).

Subsequently, comparing joints with or without condylar displacements and internal derangement of the TMJ using GEE, no significant association was found (p=0.5859). Among the joints with no condylar displacement, 27 of 54 (50.0%) had an internal derangement. Of those joints that had a condylar displacement, 62 of 112 (55.4%) had an internal derangement (Figure 13, 16).

An odds ratio calculation for magnitude of displacement and internal derangement was 2.288 (Table 1). After adjusting for direction and excluding joints with no magnitude of displacement, the odds ratio calculation was 3.925(Table 2).

Furthermore, an odds ratio calculation for medial condylar displacement (with lateral as reference) and internal derangement was 1.000 (Table 3). After adjusting for magnitude, the odds ratio was 1.000 (Table 4).

Discussion

The occurrence of disc displacements was higher in this study than seen in the general population. While the subjects in this study may not represent the general public it may be possible that there is increased incidence of disc displacements in subjects attending a dental practice. Presumably subjects with disc displacements may be more likely to seek treatment in a dental practice.

The results from this study did report significant positive associations between internal derangement of the temporomandibular joint and condylar displacement in both direction and magnitude. The superior direction showed this association when considering only the direction of the condylar displacement from deprogrammed/first contact position. No other direction showed any significant association. When considering the magnitude of condylar displacement the medial-lateral dimension, when adjusted for direction of displacement, showed a positive association while other directional planes did not.

While it was hypothesized in this study that both magnitude and direction of condylar displacement would be a risk indicator for internal derangement of the temporomandibular joint, there is both evidence to support this theory and contradictory results. The hypothesis states that a condylar displacement towards the cranial base would more likely be associated with internal derangements of the joint. This is based on the theory that joint loading would require the condylar head be forced onto the TMJ complex, including the TMJ disc, leading to the breakdown of the disc and associated structures. Analysis showed a significant difference between the superior displacement and the inferior displacement of the condyle ($p=0.0425$ and $p=0.0499$ – adjusted for magnitude). This result would support the hypothesis that displacement towards the cranial base would have a greater association with TMJ derangement. However, neither posterior ($p=0.6527$ and $p=0.8993$ – adjusted for magnitude) or medial ($p=1.0000$ and $p=1.0000$ – adjusted for magnitude) condylar displacements showed a similar relationship. Furthermore, based on the hypothesis of this study, it would be expected to have a greater association with internal derangement as magnitude of displacement increases. However, only the medial-lateral plane of direction showed this association ($p=0.0285$) when adjusted for direction.

It should be noted that when comparing condylar movements, the anatomy of the joint may explain the differences between the three planes. For example, the superior joint space averages 2.3 mm while the medial joint space averages 3.8 mm.[79, 80] It could be possible that a smaller movement of the joint in the superior direction would be more detrimental than a similar magnitude of movement of the joint in the medial direction as there is more space between the cranium and the condyle. Since the dimensions of the condyle and the fossa are different in all planes condylar displacements may have varying consequences in respects to magnitude. [81] Furthermore, the anatomical structures involved in the joint complex would likely be affected differently depending on the direction of condylar movement. Patient susceptibility should be considered when analyzing bilateral joints. In this context, since both joints were assessed separately, patients having two joints may have an increased susceptibility to internal derangement. The GEE analysis was specifically used to take into account the fact that a patient has two joints being assessed. Studies have shown that bilateral disc displacements are more common than unilateral displacements, reinforcing the idea that contralateral temporomandibular joints are both affected as they function as one unit within a patient with that individual's susceptibilities to displacement. [82-84] Since the mandible moves in three dimensions, we would be remiss not to identify the complexity of assessing condylar movements. For example, a medial movement of the condyle may be purely translational or there may be a rotational component to the movement as well. Since each directional plane is associated with condylar displacement, further analyses assessing the connections between these movements would be beneficial. These analyses are beyond the scope of this study.

Joint

The superior condylar displacement would coincide with the concept of joint loading as is supported in the literature. A superior condylar displacement as seen in this study could signify an upward force towards the glenoid fossa by the head of the condyle. This may be indicative of a greater load on the joint/disc. Should this movement be beyond the physiologic capacity of the TMJ it is theorized that internal derangements as well as other detrimental disease processes may occur. [71, 72, 74, 85]

The literature suggests that an internally deranged joint presents with signs of mechanical load. [71, 72, 85] Using a finite element analysis of the joint Abe *et al*. demonstrated that the distribution of stress during a prolonged clench differed between healthy joints and those with an internal derangement. The asymptomatic joint showed stress reduction on the condylar surface, implying that a healthy joint has the ability to dissipate the energy that exists during the clench within the soft tissues of the joint. However, an unhealthy joint with internal derangement had significantly less stress reduction. The authors hypothesized that excessive stress can lead to the breakdown of the articular disc and cartilages of the TMJ, which are the stress relieving components of the temporomandibular joint. [85] A similar study by Nickel *et al.*, using a finite element analysis, found subjects with an internally deranged disc had 1.6 times the stresses on the TMJ disc compared to that of subjects with normal joints. [12] As discussed, condylar displacement may signify a structural load placed upon the disc against a fixed object, the fossa. The greater the magnitude of this movement the more likely the stress placed upon the disc. However, in this study there was an inconsistency between the magnitude and direction of condylar displacement and internally deranged joints.

At this time the positional limitations of the condyle in the fossa are unknown. Although the condylar displacement was measured, the condylar displacement shown by the condylar position articulator does not show the relationship between the fossa and the condyles, only the change in condylar positions between bite positions. Therefore, this study cannot truly quantify load on the joint without referencing the fossa. However, by definition a load between two objects, represented here by the condyle and disc/fossa, require a static force, dynamic force, deformation, or acceleration applied between these structures. The condyle and its movements are likely the source of load in the temporomandibular joint complex.

A study by Ikeda and Kawamura using magnetic resonance and cone beam computed tomography imaging compared the joint space between patients with disc displacements and those without. They showed that the disc space increased anteriorly and decreased superiorly and posteriorly in the sagittal section. In the coronal section they observed an increase in lateral joint space and reduction in medial joint space. [86] This condyle-fossa relationship does coincide with the hypothesis of this study. Clearly a superior condylar joint displacement will reduce the joint space between the condyle and fossa; however, as previously stated there is no reference to the fossa when using the condylar position indicator. While the authors' findings have some corresponding results in respect to condylar position, their hypothesis differs. They argued that disc displacements and degeneration of the joint/disc complex initiate the loss of joint space whereas this study hypothesized that the condylar displacement causes the deleterious effects on the disc leading to displacement. Arguments can certainly be made for both hypotheses. [87-89]

An ongoing debate in dentistry revolves around an ideal condylar position. Okeson described an optimal orthopedically stable joint position as a harmonious relationship between the condyles and the articular fossa where the articular discs are properly positioned between them. The condyles take this position when the elevator muscles are activated with no influence from the dentition. When these muscles function optimally only then can the joint be deemed orthopedically stable and musculoskeletally stable. [8] In essence Okeson described a temporomandibular joint that functions soundly through proper muscular function and occlusal relationships and any deficiencies in these systems could lead to an unfavorable joint position. This is essentially a condylar displacement mediated by either poorly functioning muscles or improper occlusal relationships. In this study we used a muscularly mediated condylar position (deprogrammed/first contact position) to compare condylar position mediated by the dentition (MIP). Therefore in this study we are assessing both the effects of the muscles and the dentition on the position of the condyle and the potential effect on the temporomandibular joint. The results may indicate that a dental disharmony may cause an improper joint position leading to internal derangement of the joint. Conversely, these results may indicate a muscular issue whereby the dentition is adversely affected leading to condylar displacement.

Muscles

The musculature responsible for elevating the mandible is presumably the source of force in temporomandibular joint complex as well as the dentition. Muscle activity could be associated with functional activity such as mastication, speech and swallowing as well as non-functional mandibular movements. This may include bruxism, clenching and increased muscle tonicity related to habits or posture. Several studies have shown the relationship between the musculature, bruxism and temporomandibular joint disorders. [90-93] A study by Raphael *et. al.* revealed increased masticatory muscle electromyographic activity in patients with myofascial temporomandibular disorders. [94] Increased muscle activity would theoretically produce two sources of pressure, along the dentition and at the condylar level.

An acute malocclusion may result from a sudden change in the resting length of the masticatory muscles that control mandibular position. [95] Furthermore, it is theorized that occlusal contact patterns of the teeth will influence the activity of the masticatory muscles and vice versa and therefore a relationship is hypothesized. However, the manner in which the occlusion affects muscle activity and vice versa is not clearly established. [8] The reciprocity in this relationship between the muscles and occlusion is theorized to make the assessment of the effect of occlusion on TMD difficult. The muscles are said to hide the nature of the condylar malposition and erroneous closing stroke through muscle memory[65]

Based on the literature, many studies have shown that the muscularly deprogrammed position allows for the "ideal" condylar position and deviations from this position may be associated with TMJ derangement. [96-99] This study uses two condylar positions as points of reference: MIP and a deprogrammed position. By using a deprogrammed position, this study makes the assumption that any condylar deviation to MIP from a deprogrammed position would signify movement away from the norm. However, as previously mentioned, "ideal" condylar position at this point is speculative. While this study measures the changes in condylar position from a joint position that may not be confirmed as the most favorable condylar position there may be value in measuring the change. Such change may signify disharmony between the joint, muscles and dentition irrespective of an ideal position

In this study it was determined that in the anterior-posterior direction 141 joints (84.9%) moved to a neuromuscularly deprogrammed position, 134 joints (80.7%) in the inferior-superior direction and 112 joints (67.5%) in the medial-lateral direction. This may be an indication that most maxillomandibular relationships do not align perfectly with muscle function. However, this may not necessarily coincide with an increased risk of internal derangement. The structures of the TMJ likely have an adaptive capacity to such movements. Since this study found that a superior displacement of the joint may be a risk indicator for internal derangement it may be possible that the adaptive capacity in this direction is less amenable.

Occlusion

Mehta *et al.* stated that in order to have a stable dental occlusion, there must be harmonious function between muscles, TMJ position, and occlusion in the closing stroke.[1] If the teeth do not allow the mandible to close smoothly in its path to full closure, the muscles will react aberrantly, leaving the TMJ in a strained position. At the point of first tooth contact the dentition takes over the guidance of the mandible to full closure. If there is an inconsistency between the muscular path of closure and the initial tooth contact, the mandible will shift to fully close. The shift of the mandible and presumably the condyles is surmised to play a lead role in occlusal mediated temporomandibular joint issues. It is presently understood that not all occlusal interferences are detrimental, only those that cause a condylar shift. Further, on full closure, teeth act as a “doorstop” for the TMJ. The dentition may not only position the condyles properly in the fossa but also protect the joint from masticatory forces. [1] Okeson summarized that the "problems with bringing the teeth into occlusion are answered by the muscles. However, once the teeth are in occlusion, problems with loading the masticatory structures are answered in the joints". [8]

Most functional activity occurs at or near the MIP. Although the MIP position may not always be the most musculoskeletally stable position for the condyles, it is stable for the occlusion because of the maximum number of tooth contacts it provides. Therefore the forces of functional activity are distributed to many teeth, minimizing the stress placed on an individual tooth.

The protective mechanisms associated with the dentition and periodontium seem to be highly equipped to accept the stresses placed on the masticatory system whereas the joint is not. The disc being an aneural and avascular piece of cartilage seems an unlikely source of adaptive response and support for these stresses. If condylar position is dictated by occlusion then it would stand to reason that occlusion may indeed have a role in temporomandibular joint disorders. Furthermore, if condylar position is associated with increased loading of the temporomandibular joint, which has been shown to be associated with joint pathology, positional instability of the occlusion may be the detrimental factor. Mehta *et al.* proposed the concept of three-dimensional assessment of the maxillomandibular relationships called "the occlusal fencing concept". [1] They stated that the maxilla acts as the fence to the mandible whereby controlling the position of the mandible on closure. This concept takes into account the three dimensional positioning of the mandible in space and proposes an anterior-posterior, medial-lateral and superior-inferior fence. Similarly, this study considers the three-dimensional movement of the condyles.

The importance of the positioning of the mandible has been noted previously in the literature. Dawson states that disharmony between centric relation of the jaw and articulation of the teeth can cause hypersensitivity, excessive wear, and hypermobility of the teeth. [66] Jankelson stated that when centric occlusion does not coincide with the neuromuscular position, proprioceptive feedback from the mouth position in centric occlusion dictates a strained muscle accommodation and an accommodated trajectory of closure. [23] The posterior displacement of the mandible is theorized to be caused by several occlusal factors (anterior-posterior fence). The tip and torque of the maxillary incisors may cause a ramp for the mandible to retrude posteriorly on closure. It should be noted that such a vector may also include a superior direction of condylar movement. In this study the superior direction of condylar displacement was associated with internal derangement of the joint while the posterior displacement was not.

The dentition is considered by dentists as the main determinant of the vertical dimension of occlusion (VDO) (superior/inferior fence). However, the dentition is housed by alveolar bone and positioned by the musculature. Therefore all three should be considered when assessing VDO. Mehta *et al.* maintain that the superior fence of the maxilla establishes the vertical height of the mandible and condyle relative to the maxilla and fossa. Changes in the VDO, whether due to wear on the dentition or position of the dentition would cause a superior movement of the condyle and may be detrimental to the joint. [1] This study would seem to correlate with the idea of the dentition vertically supporting the mandible and condyle.

The lateral positioning/fence as described by Mehta *et al.* discusses the positioning of the mandible lateral to the midline (medial on the contralateral joint). Furthermore, they discuss the tendencies of the dentition to change position along the arch form to accommodate the opposing teeth. They theorize that such accommodation may lead to dental imbalances. These imbalances of the dentition may lead to imbalances of the muscles and possibly the joint.

While this study focused on the condylar position it is unknown how the dentition and musculature creates this change. The dentition may create a fulcrum in which the mandible may pivot around or create a slope which creates directional changes of the mandible upon closure. It may also create rotations in the axis of the mandible. Three dimensional analysis of occlusion is required to understand how it may affect the condyles and subsequently the temporomandibular joint. Further research where the movement of the mandible, including the condyles, is measured as one entity is required to understand the effect of occlusion on condylar position. This would require instrumentation that can record such movements that a condylar position indicator cannot.

Such a change in occlusal concepts may change the methodology of many dental concepts such as prosthodontic rehabilitations, orthodontic correction and TMD therapy. Should a mandibular shift indeed be a risk indicator for disc displacements, occlusal measures of this sort may become prophylactic diagnostic measurements to help reduce risk factors in possible temporomandibular joint derangements. Measurements of this type are not presently a mainstay of a routine dental assessment.

Furthermore, not only could such a result shed light on dental occlusion/condylar position concepts but may also create new avenues of thought about disc displacements and other temporomandibular joint disorders. In the future, newer investigative techniques that are more sensitive to minor changes will be required to understand these complex problems such as malocclusion, condylar position, joint loading and temporomandibular disorders.

It may be the incongruence between the dentition that places the condyles in an unfavorable position. This incompatibility between the maxilla and mandible may be represented by a discrepancy in the maxillomandibular relationship which would invariably cause a condylar displacement as reported in this study.

The role the dentition plays in temporomandibular joint disorders has always been a source of controversy within dentistry. However, the anatomical relationship is clear. The dentition determines the terminal stop of the closing movement of the mandible and therefore also the terminal stop for the condyle within the fossa.[2, 69, 85, 100] Therefore this association cannot be dismissed. Occlusion is most often described as a tooth-to-tooth relationship and therefore not a measure of the position of the joint in the fossa even though anatomically related. If the dentition is unable to support the condyle in the proper position in the fossa, this could lead to further instability of the joint and perhaps internal derangements of the joints. Internal derangements caused by joint loading caused by condylar displacement caused by an orthopedically unstable occlusion may have some merit based on the literature and this study.

Conclusion

The present study supports the hypothesis that both the direction and magnitude of condylar displacement may be a risk indicator for internal derangement of the temporomandibular joint, however, inconsistently in all planes of movement. The association was observed in the superior direction; however, none was found in the other planes of direction. Furthermore, the magnitude of condylar displacement in the medial-lateral direction, when adjusted for the direction of displacement, may be a risk indicator for internal derangement; however, a similar association was not found in the other planes of direction. It is unclear at this time why condylar displacement may be associated with internal derangement of the joint in only the superior direction and the magnitude of displacement in the medial-lateral plane. Follow up studies with a larger population of subjects may be needed to address this question.

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Appendix A: Tables

	Magnitude (p-value)	Odds Ratio	95% CI
Anterior-Posterior	0.6289	1.049	0.864-1.273
Inferior-Superior	0.7803	1.050	0.745-1.479
Medial-Lateral	0.0564	2.288	0.978-5.352

Table 1. Generalized Estimating Equations analysis of magnitude of condylar displacement and internal derangement of the temporomandibular joint.

	Magnitude adjusted for direction (p-value)	Odds Ratio	95% CI
Anterior-Posterior	0.3177	1.123	0.894-1.411
Inferior-Superior	0.7471	1.062	0.736-1.533
Medial-Lateral	0.0285*	3.925	1.154-13.346

*Joints with zero magnitude of displacement were excluded

Table 2. Generalized Estimating Equations analysis of magnitude of condylar displacement (adjusted for direction) and internal derangement of the temporomandibular joint.

	Direction (p-value)	Odds Ratio	95% CI
Posterior (Anterior as reference)	0.6527	1.231	0.497-3.048
Superior (Inferior as reference)	0.0425	2.407	1.030-5.623
Medial (Lateral as reference)	1.0000	1.000	0.531-1.884

*Joints with zero magnitude of displacement were excluded

Table 3. Generalized Estimating Equations analysis of direction of condylar displacement and internal derangement of the temporomandibular joint.

	Direction adjusted for Magnitude (p-value)	Odds Ratio	95% CI
Posterior (Anterior as reference)	0.8993	1.065	0.400-2.835
Superior (Inferior as reference)	0.0499	2.349	1.000-5.518
Medial (Lateral as reference)	1.0000	1.000	0.516-1.938

*Joints with zero magnitude of displacement were excluded

Table 4. Generalized Estimating Equations analysis of direction (adjusted for magnitude) of condylar displacement and internal derangement of the temporomandibular joint.

Appendix B: Figures

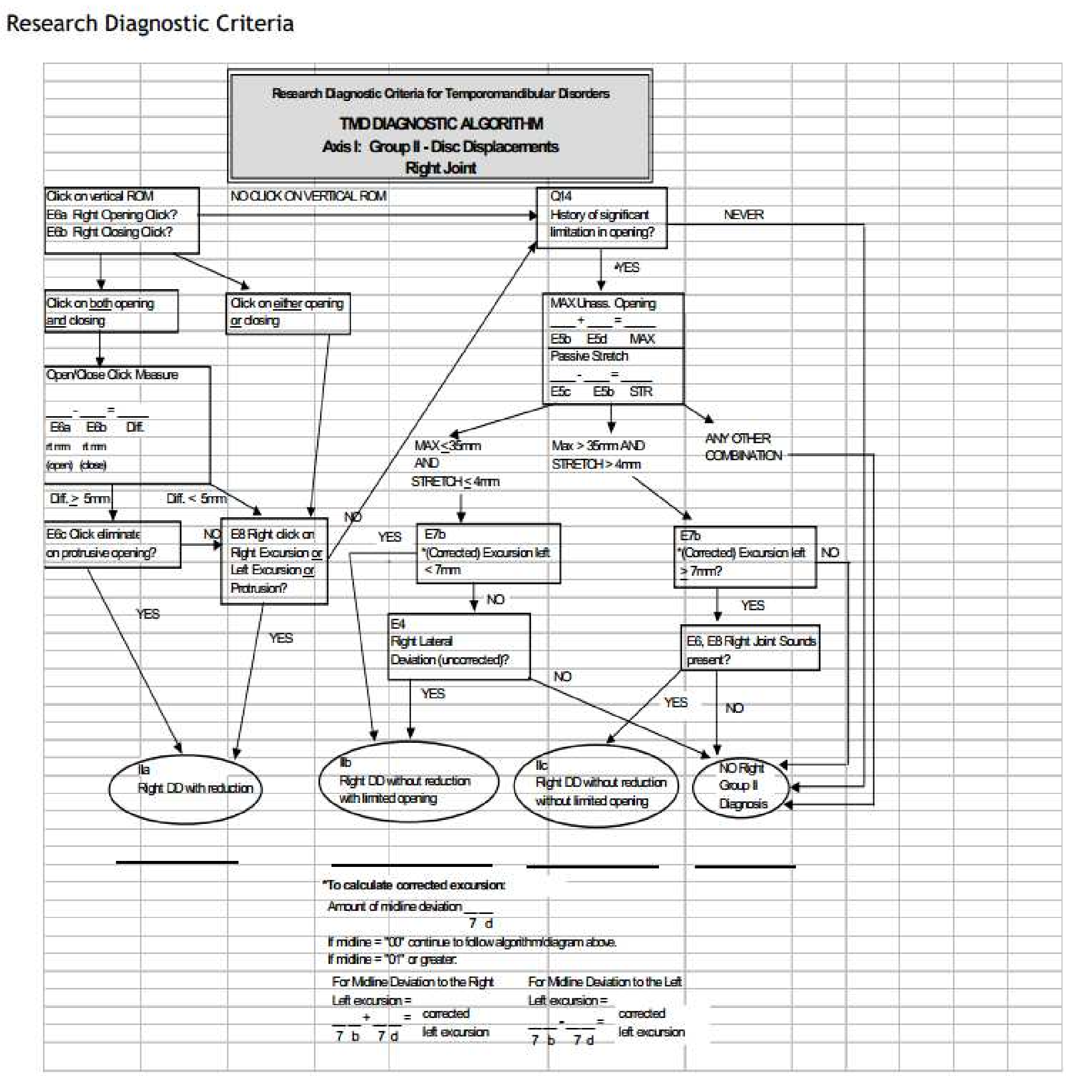


Figure 1. Research Diagnostic Criteria for Temporomandibular Disorders. TMD Diagnostic Algorithm Axis I: Group II – Disc Displacements

Figure 2. Panadent CPI – III Condylar Position Indicator

Figure 3. MIP Bite Registration of study subject.

Figure 4. First Tooth Contact/Deprogrammed Position Bite Registration of same study subject.

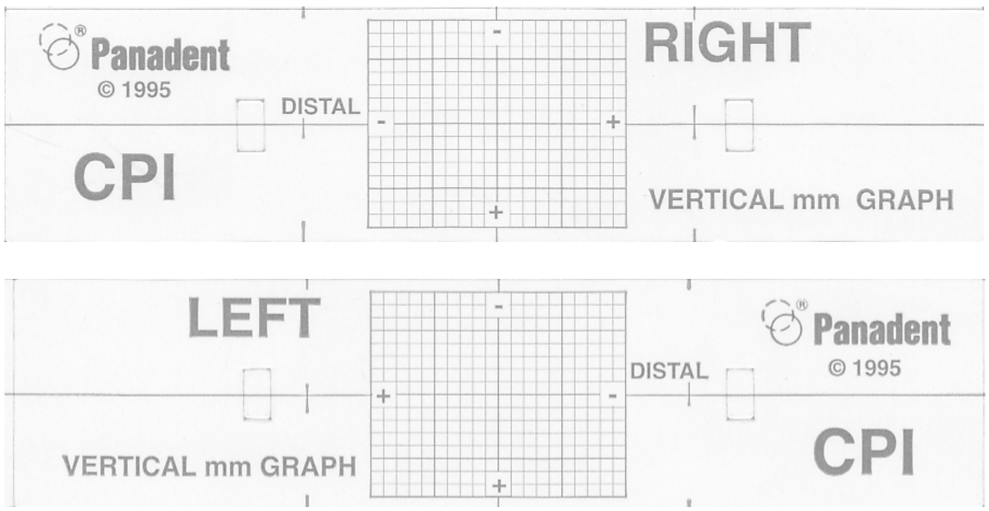


Figure 5 Panadent CPI – III Graph Paper - Right and Left Joint Vertical Graph

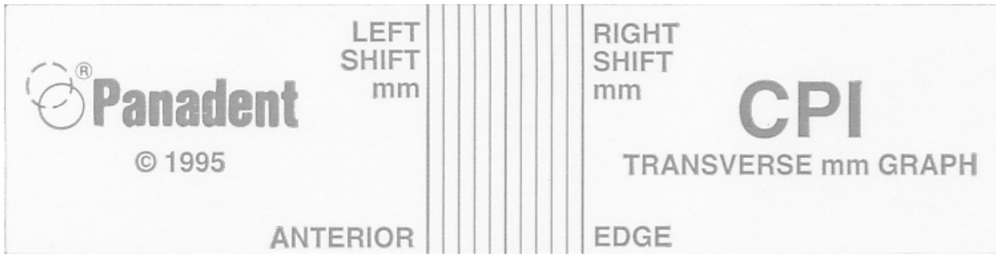


Figure 6. Panadent CPI – III Graph Paper - Transverse Graph

Data Sheet Protocol Legend

ID: Internal Derangement

FC: First Contact Position (change in distance from MIP)

A-P: Anterior – Posterior (with Posterior being positive)

I-S: Inferior – Superior (with Superior being positive)

M-L: Medial – Lateral (with Medial being positive)

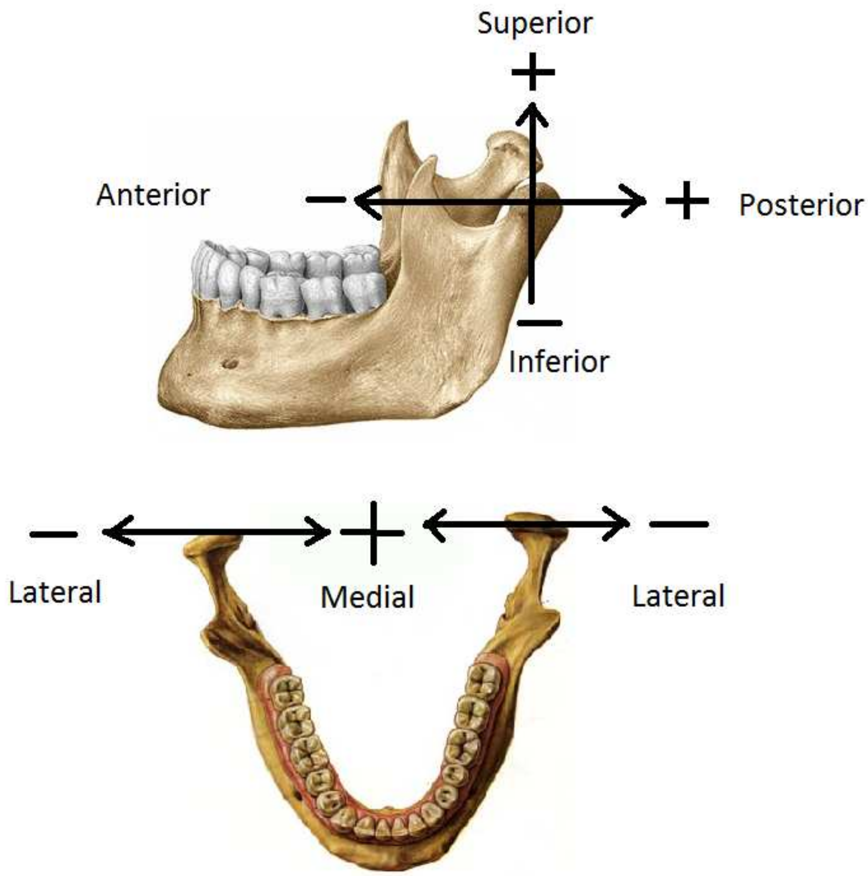


Figure 7. Data Sheet Protocol Legend

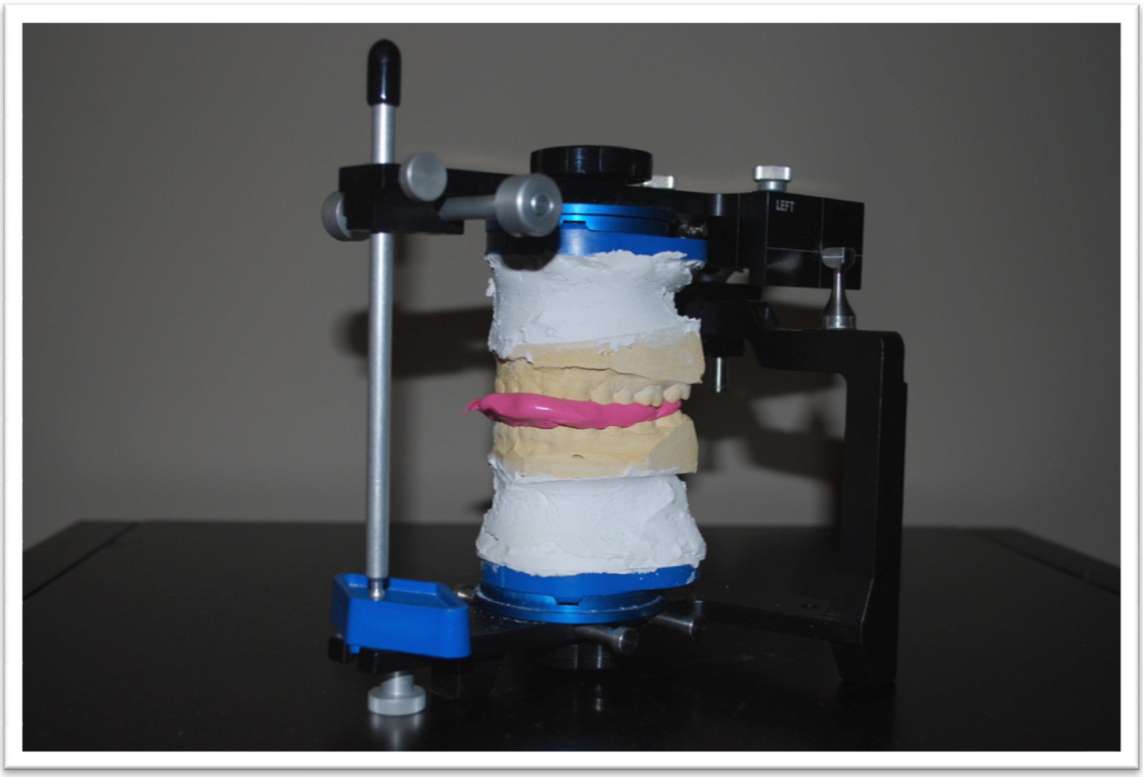


Figure 8. Panadent Condylar Position Indicator Articulator

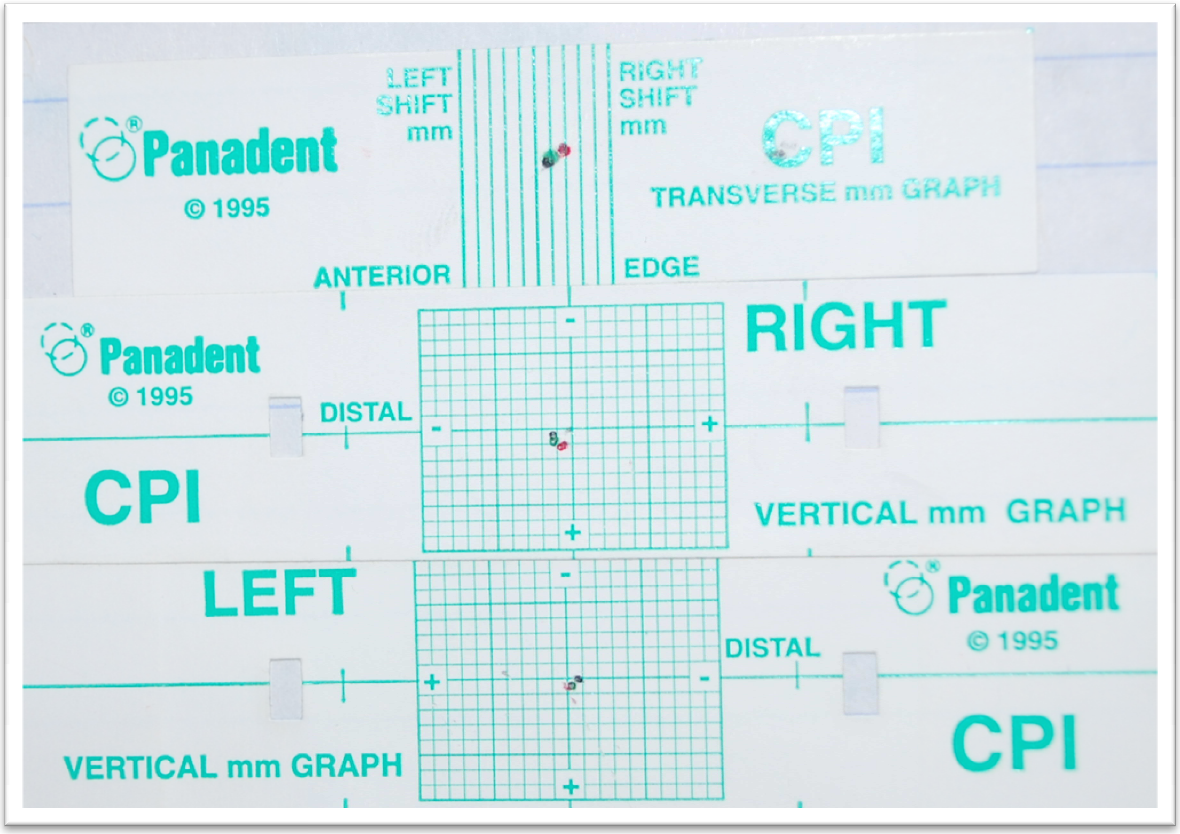


Figure 9. Panadent CPI – III Graph Paper Recordings

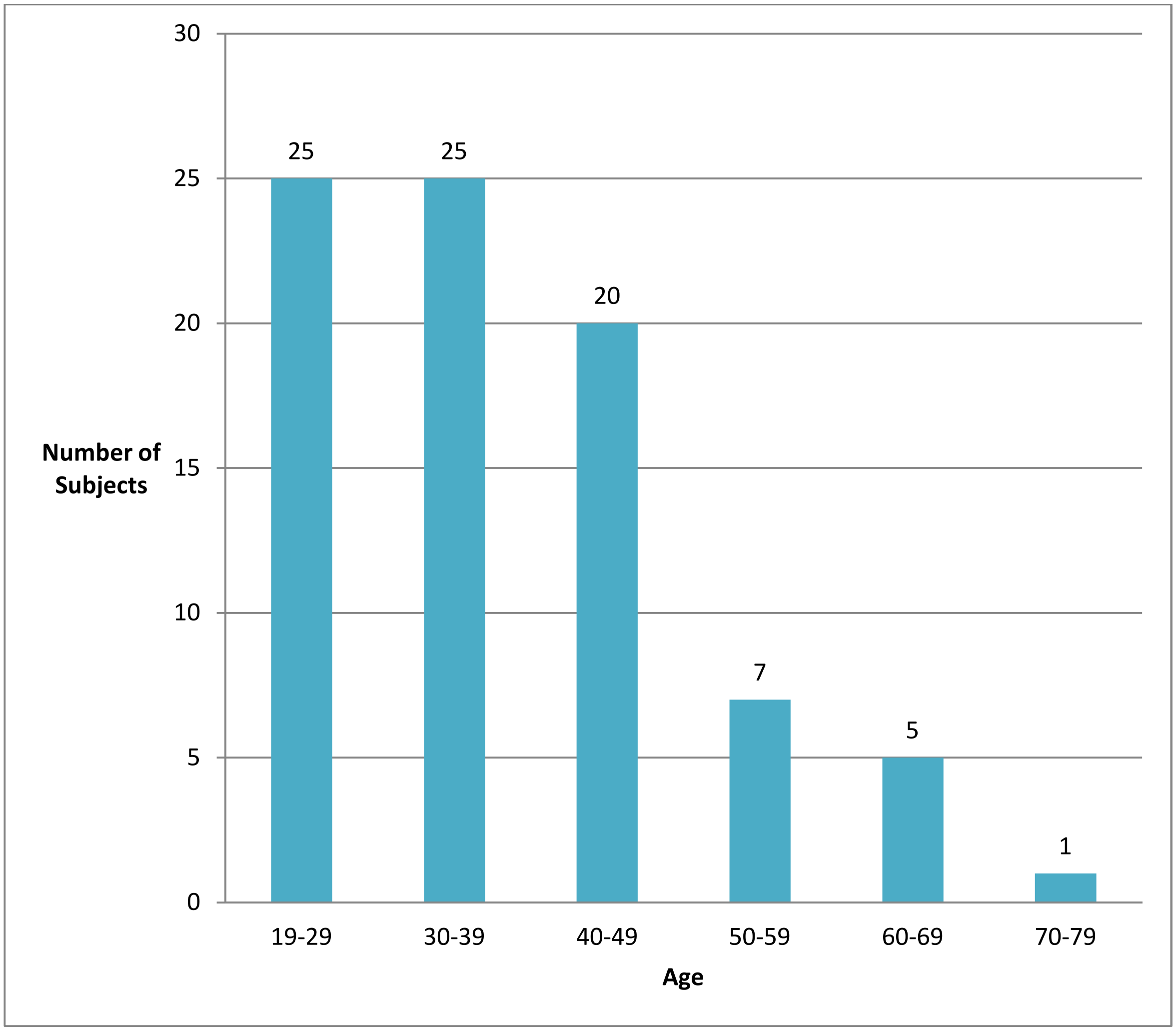


Figure 10. Subject demographics: Age distribution (n=83). Mean age of 38 (SD=12)

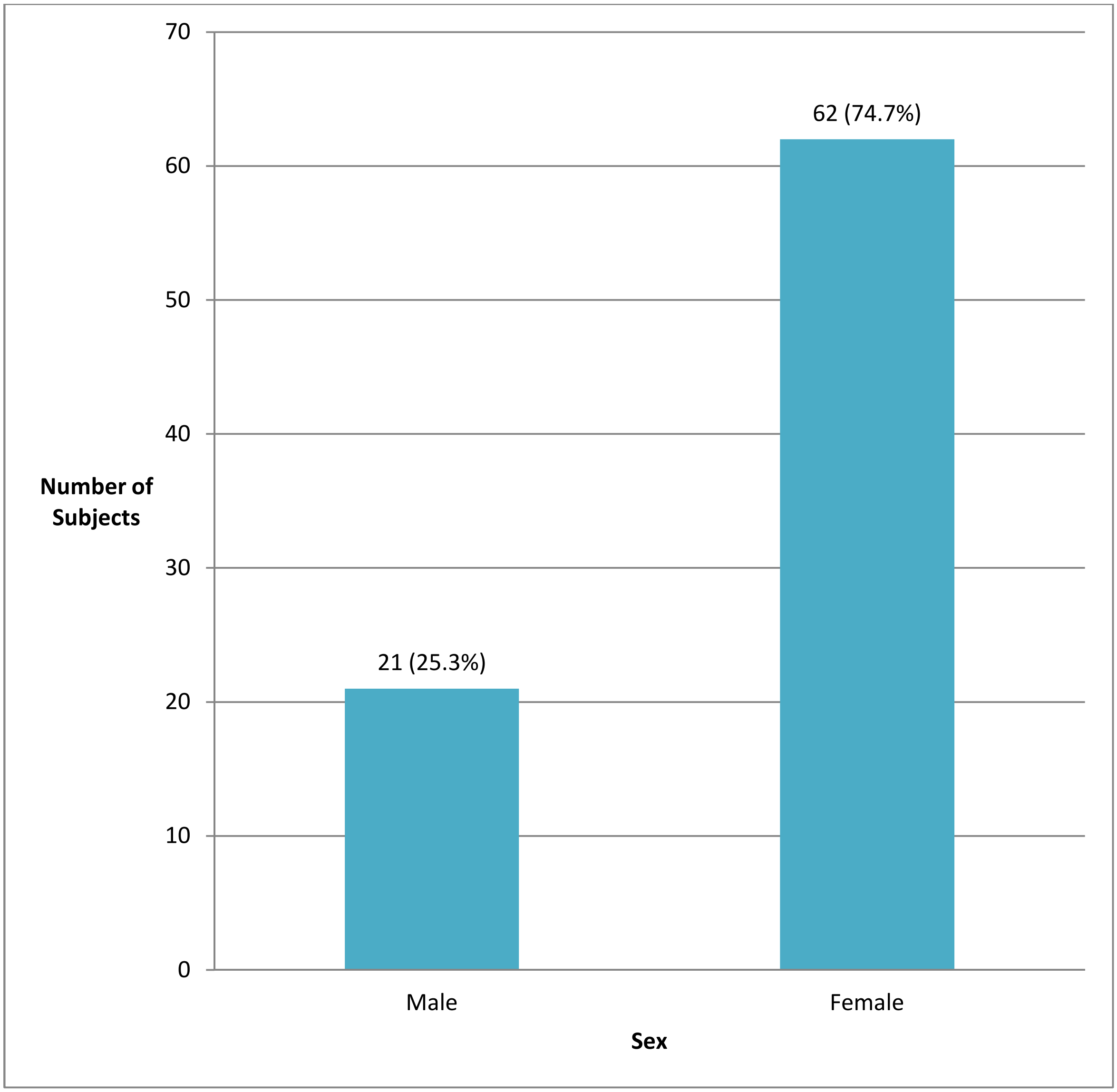


Figure 11. Subject demographics: Sex (n=83)

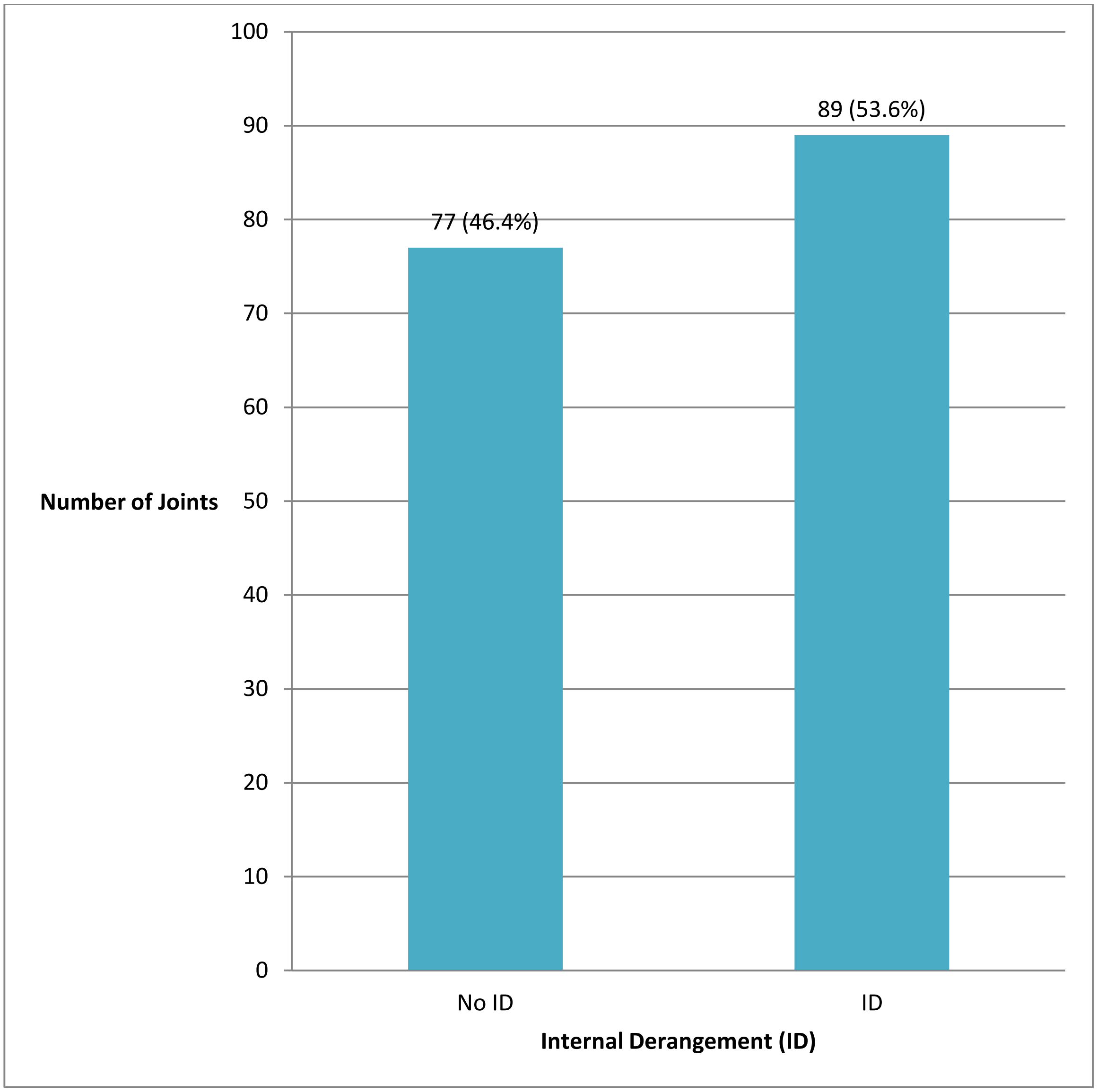


Figure 12. Internal derangement (ID) of individual temporomandibular joints (n=166).

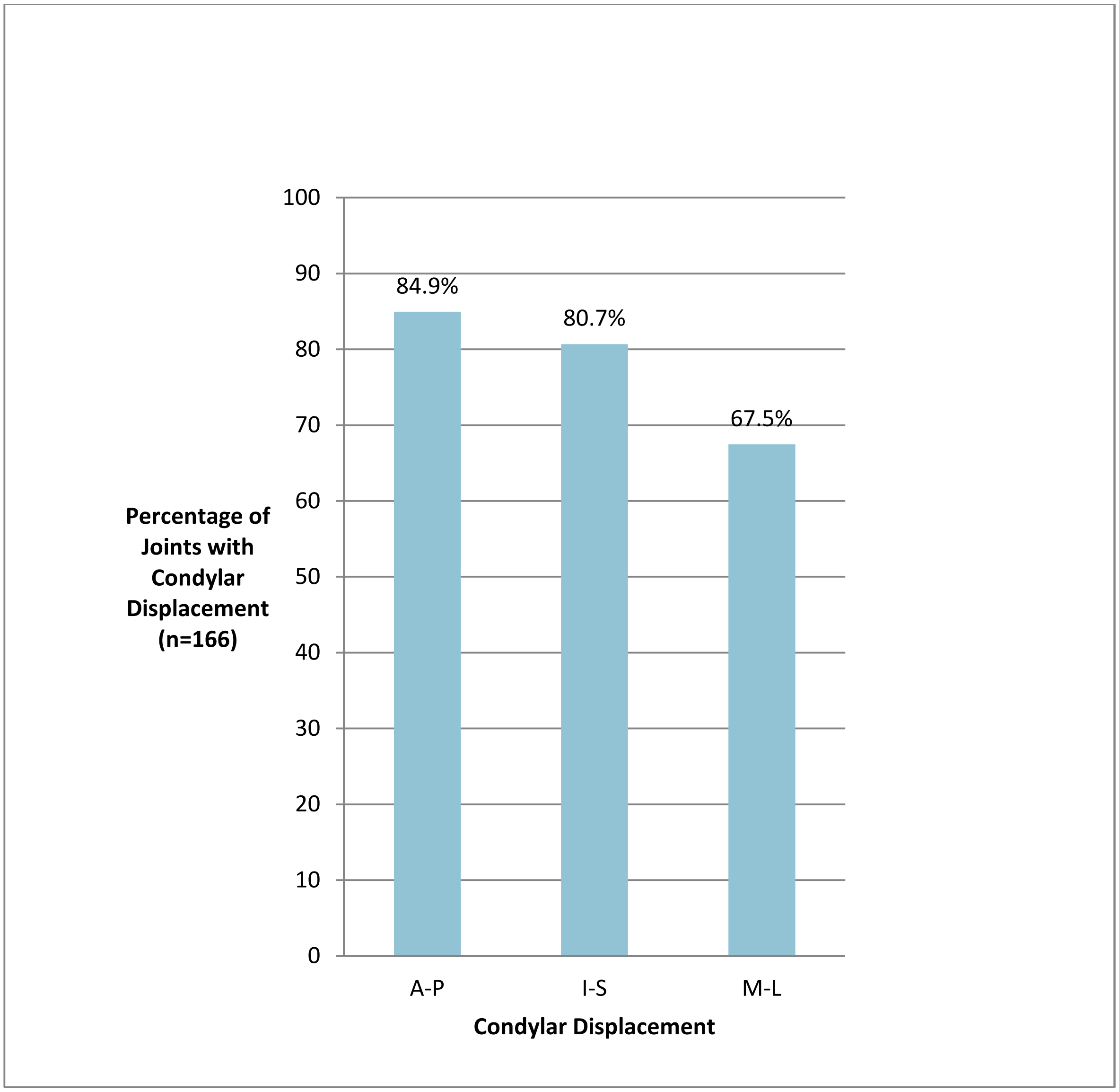


Figure 13. Percentage of joints with condylar displacement in each directional plane of individual joints.

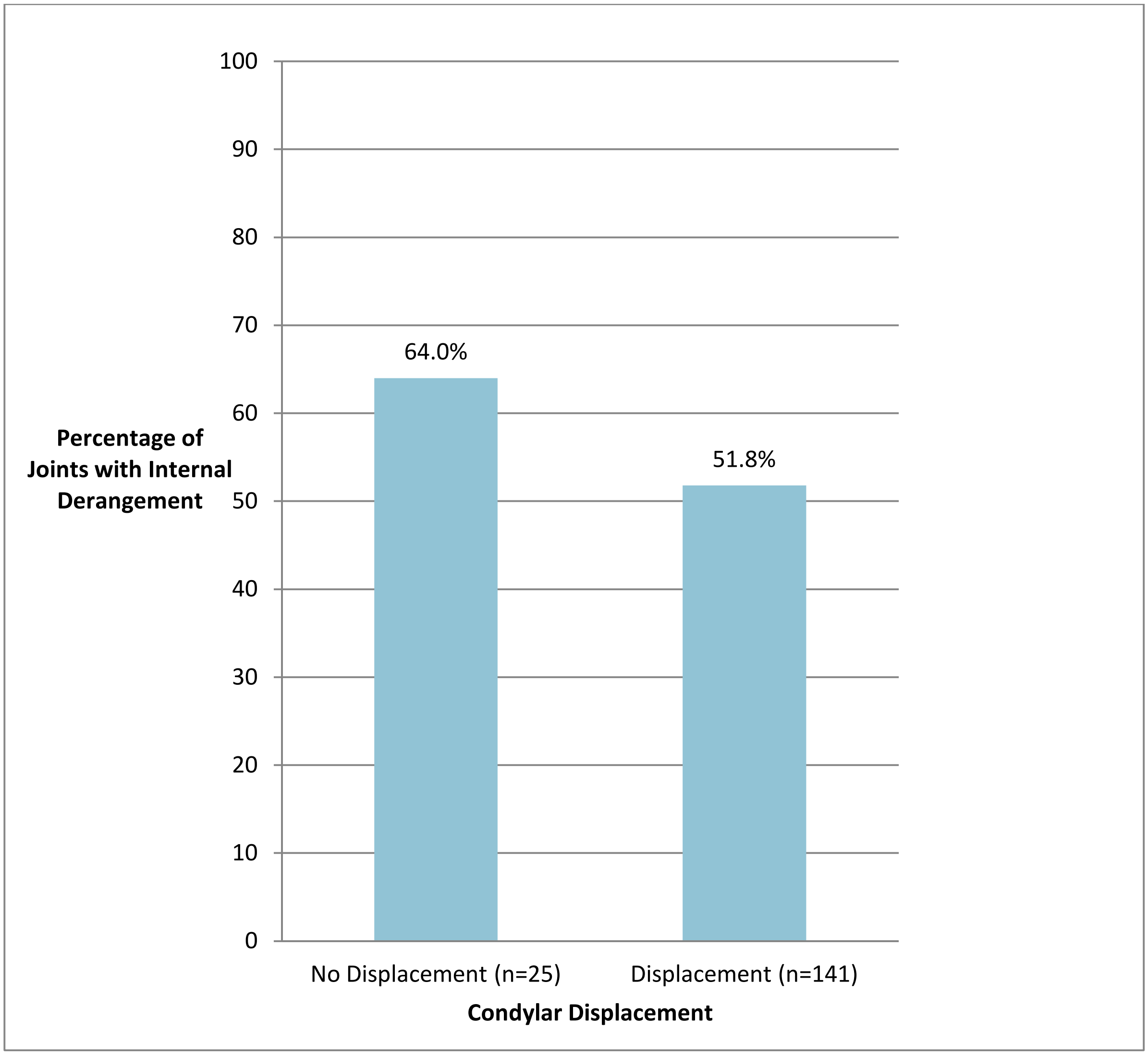


Figure 14. Comparison between individual joints with and without Anterior-Posterior condylar displacement and internal derangement (n=166, p=0.1257).

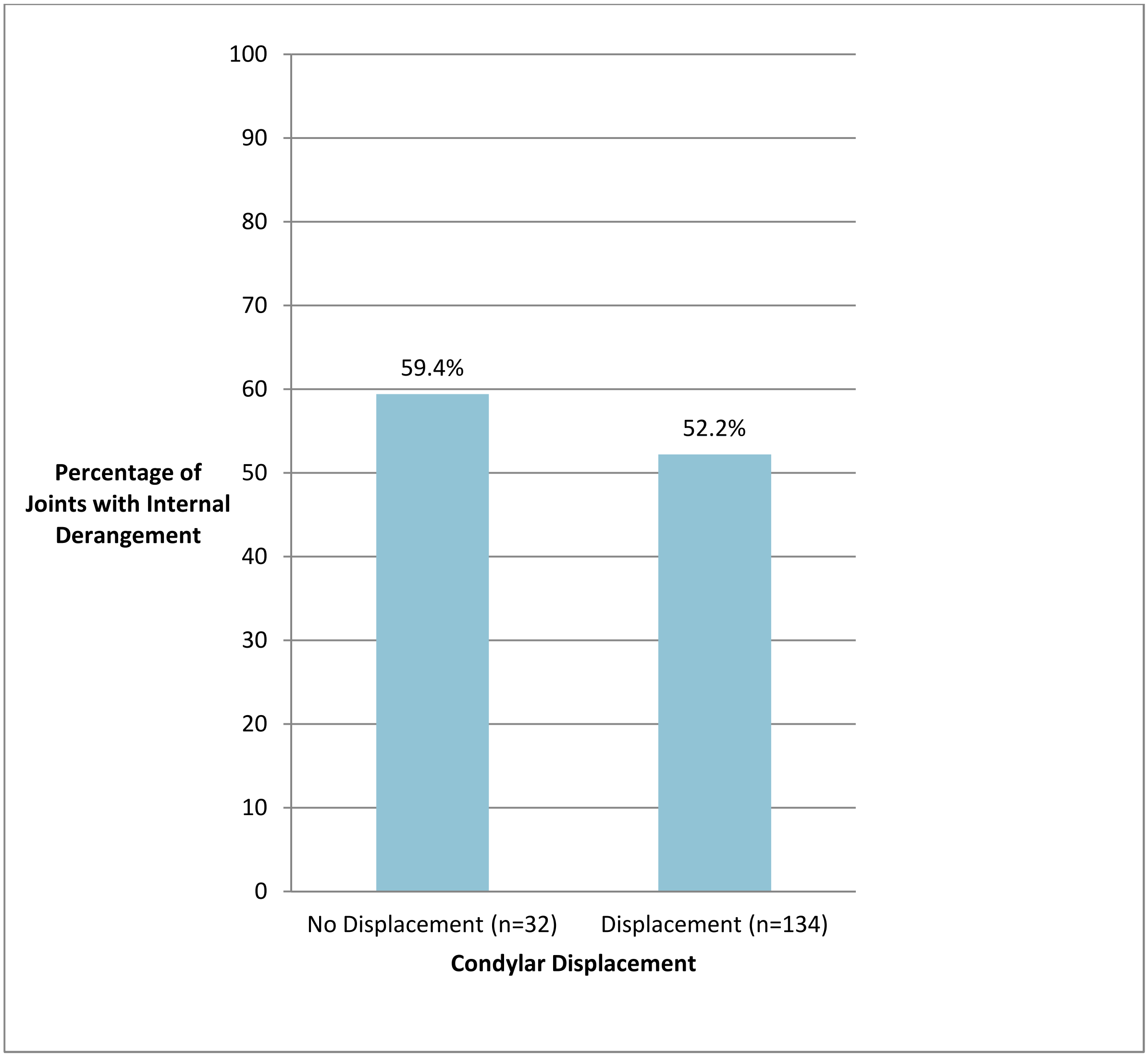


Figure 15. Comparison between individual joints with and without Inferior-Superior condylar displacement and internal derangement (n=166, p=0.3090)

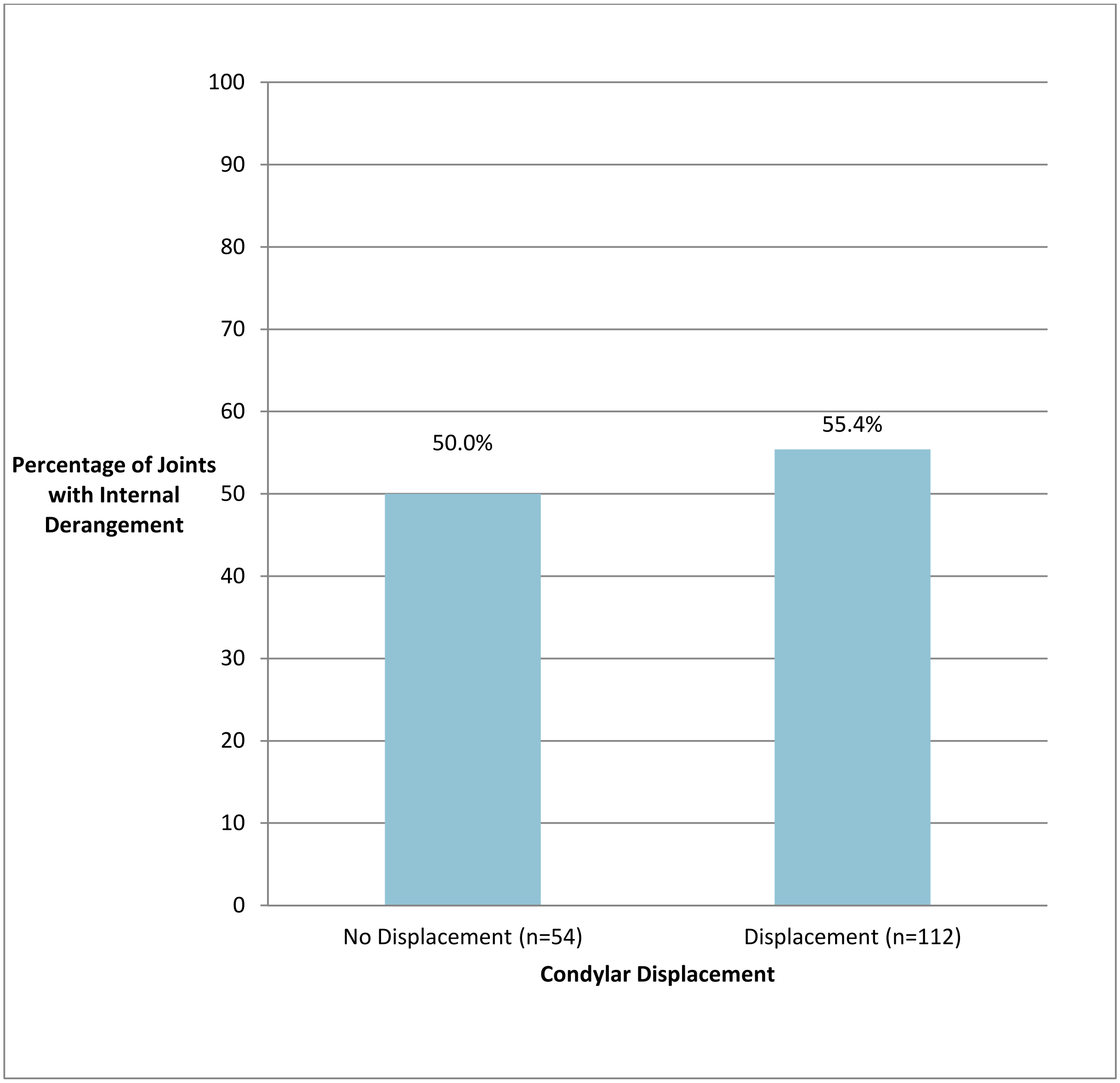


Figure 16. Comparison between individual joints with and without Medial-Lateral condylar displacement and internal derangement (n=166, p=0.5859)

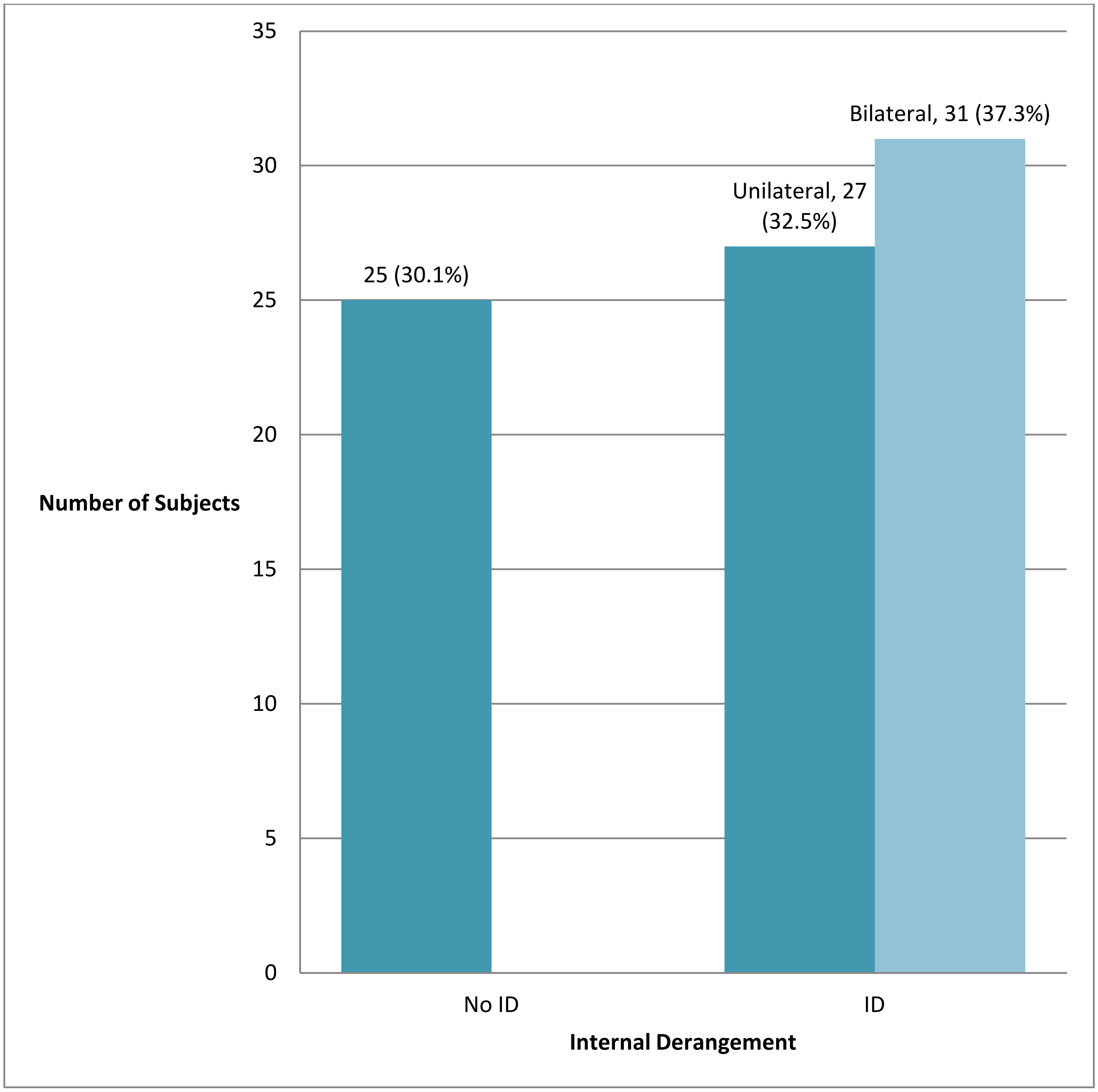


Figure 17. Internal derangement (ID) of individual subjects (n=83).

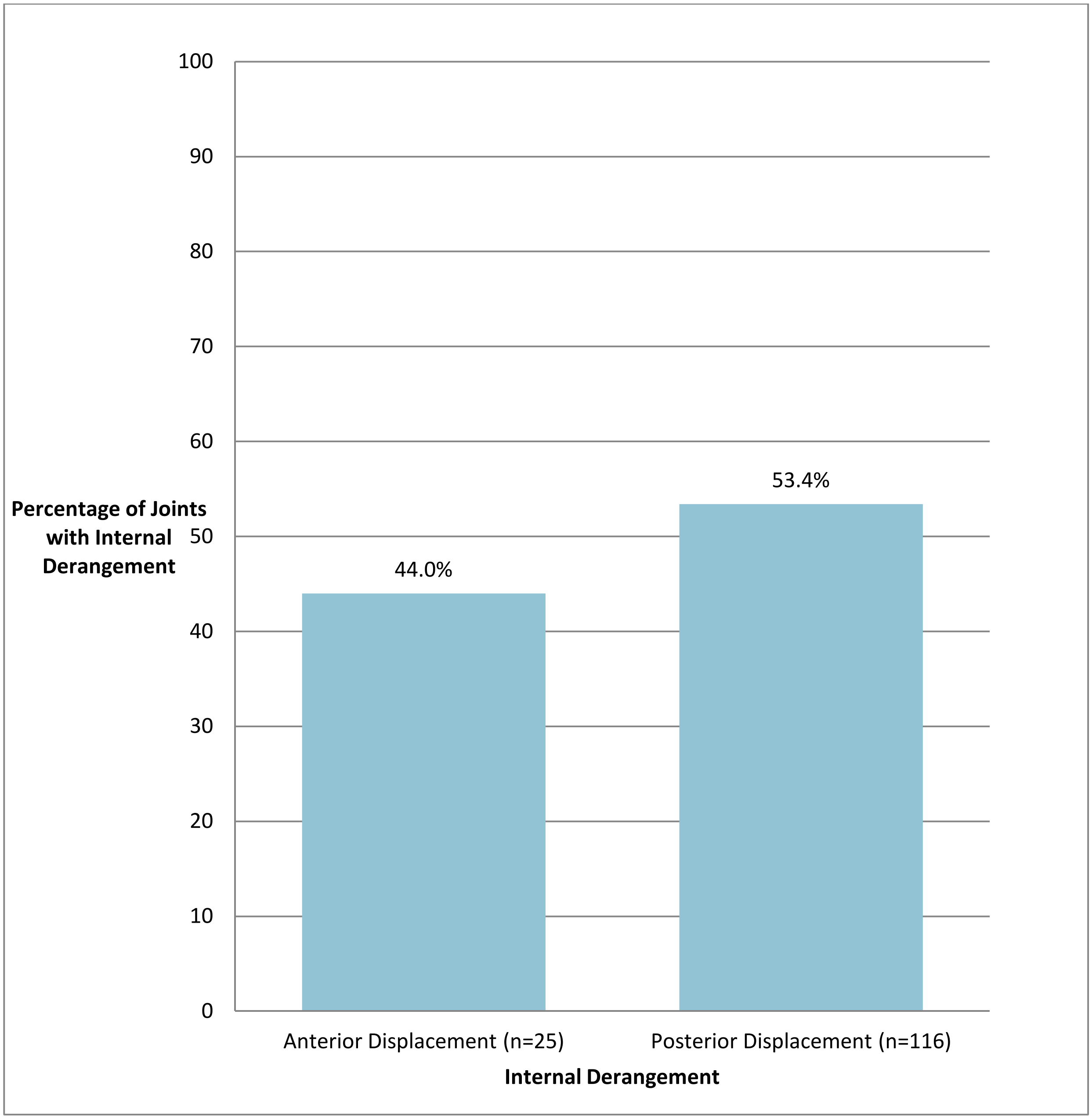


Figure 18. Comparison of Internal derangement (ID) of joints with Anterior-Posterior Condylar Displacement (p=0.6527)

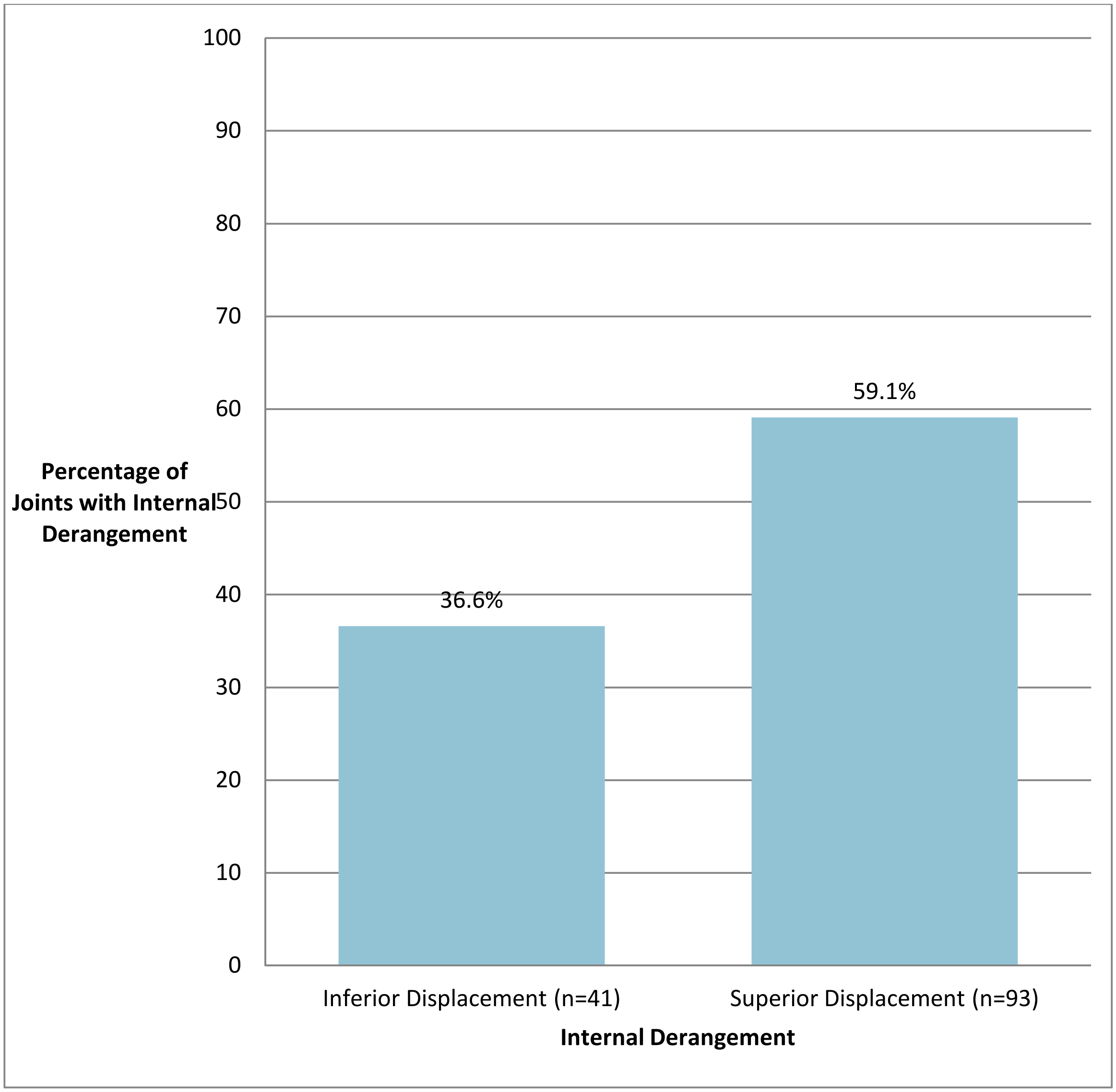


Figure 19. Comparison of Internal derangement (ID) of joints with Inferior-Superior Condylar Displacement (p=0.0425)

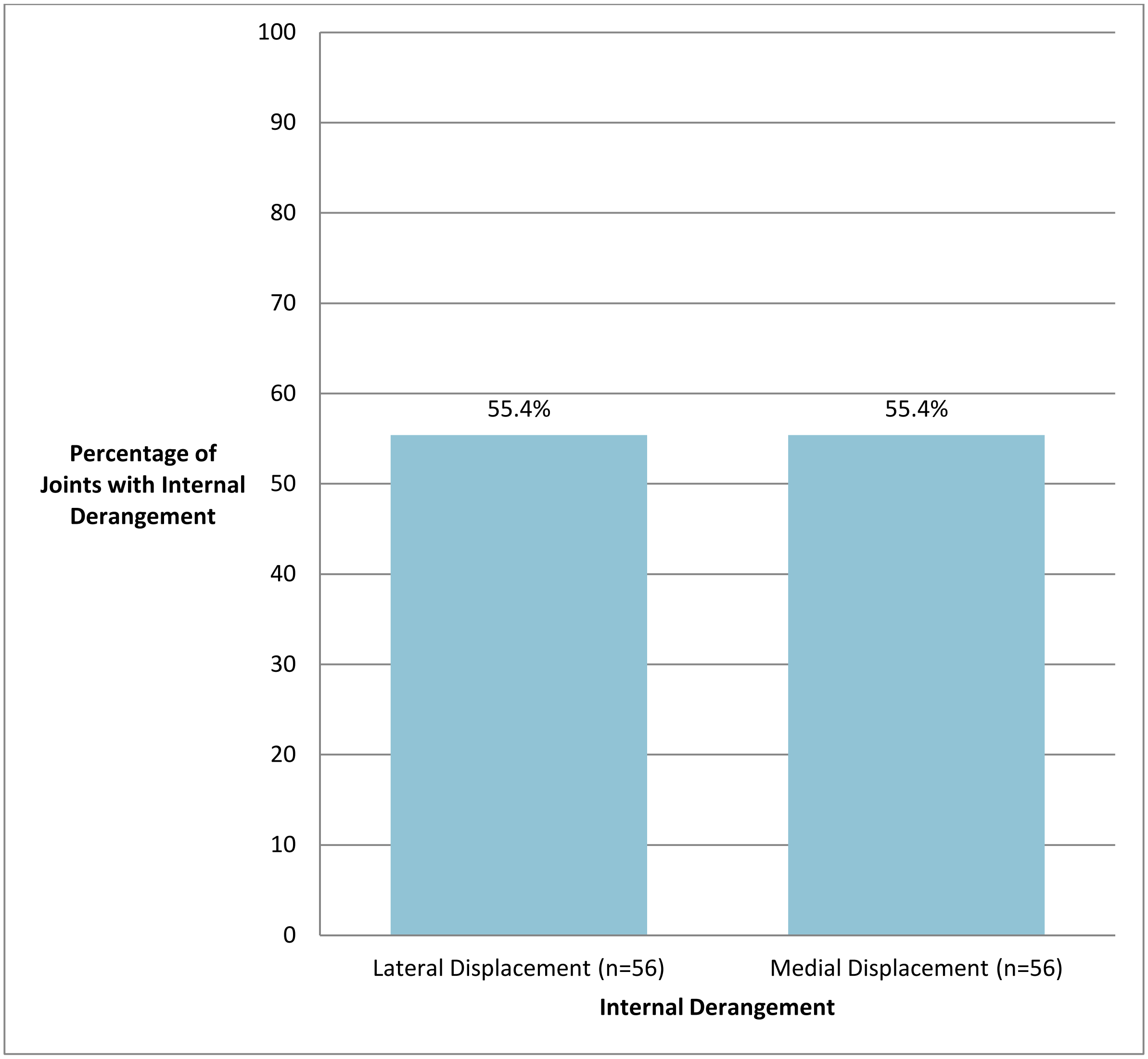


Figure 20. Comparison of Internal derangement (ID) of joints with Lateral-Medial Condylar Displacement (p=1.0000)

Appendix C: Bite Registration Techniques

All bite registrations will be taken with the patient sitting in an upright position.

MIP Bite Registration

Subjects will be asked to bite into a polyvinyl siloxane (PVS) bite registration material where all their teeth are interdigitated into their reproducible MIP.

Deprogramming and 1st Contact Bite Registration

Subjects will be instructed to hold a cotton roll between their maxillary and mandibular incisors for 5 minutes with little to no tension in their facial muscles. After 5 minutes the cotton roll will be removed. Subjects will be instructed to gently close their mandible until 1st contact between a maxillary and mandibular tooth is achieved (multiple teeth may contact simultaneously). Subjects will then be asked to tap their teeth several times in that position until the subject can predictably occlude in that position. Subjects will then occlude on that 1st point of contact with a piece of dental articulation paper (AccuFilm®) placed between the occluding teeth. The subjects will then be asked to bite into the "1st contact position" with PVS bite registration material placed between the dentition. The 1st contact bite registration will be verified by comparing the burn out on the PVS bite registration material with the occlusal markings created by the articulation paper. This will be repeated until the bite registration can be verified to the occlusal markings.

Appendix D: Panadent Condylar Position Indicator III Instructions

Panadent

CE 0470

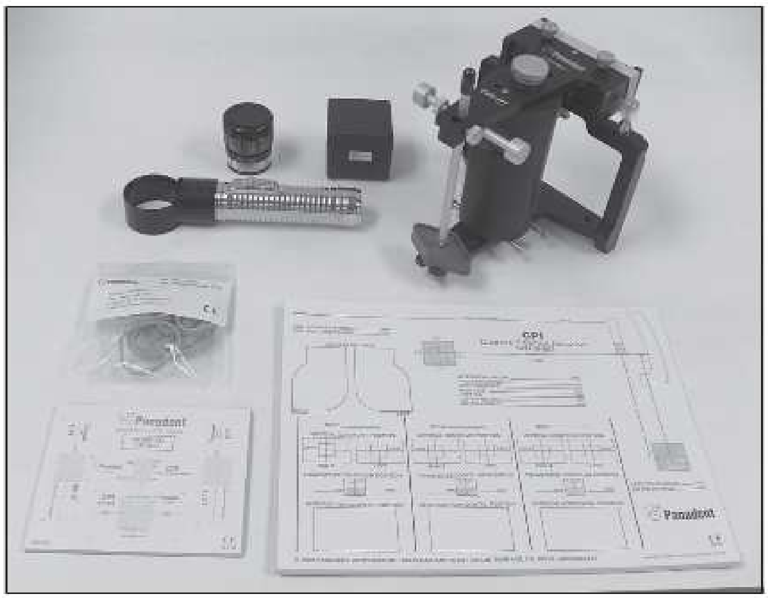
Panadent Corporation
580 S. Rancho Avenue • Colton, California 92324, USA
Tel: (909) 783-1841 • USA & Canada (800) 368-9777

These instructions apply to the following items:

REF 2500
Includes:
9611
9615

CPI - III Instructions

Condylar Position Indicator



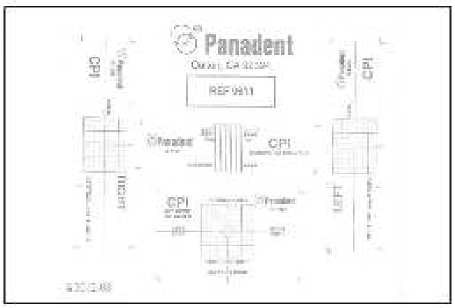
Complete *CPI-III Nomenclature*

- a) 2501 CP CPI - III Maxillary and mandibular frames with support column
- b) 9611 CP Graph papers (20 sets)
- c) 9615 CP Data record sheets (50)
- d) 2550 CP Elastic support bands (12)
- e) 9354 CP Optical resolver and illuminator (Optional)

2

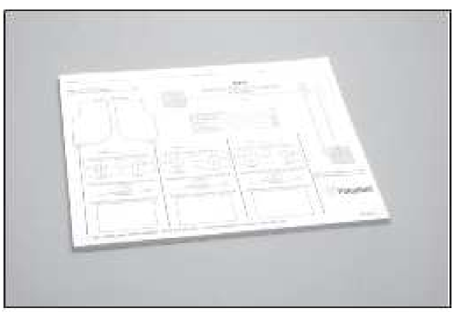
Maxillary and mandibular CPI frames joined together with inter-frame support column

3



Graph papers (pad of 20 sets)

4



Patient record sheets (pad of 50)

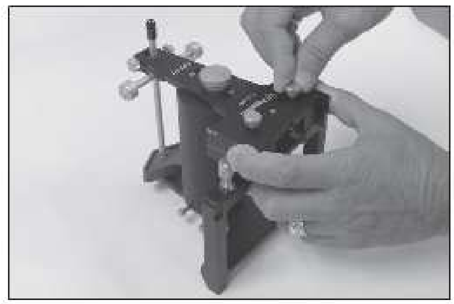
5

Elastic support bands

OPTIONAL: Optical resolver and illuminator with lens protector (batteries not included)

6

Remove rubber safety band around vertical graph support of CPI. Lock both vertical graph supports (with associated thumbscrew) firmly in contact with maxillary frame. (Do not over-tighten thumbscrews.)

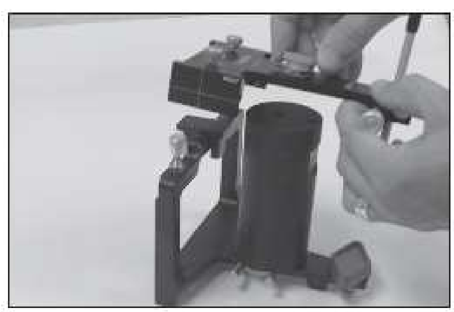


7

Raise and lock anterior support pin about five (5) centimeters above plastic incisal table.

8

Loosen mounting plate thumbscrew and remove maxillary frame from inter-frame support column. Do not force or bind precision locating dowels when removing frame from support column.

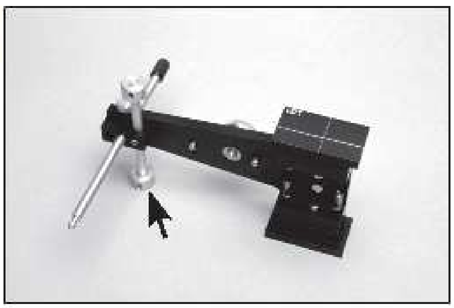


9

10

Pull soft plastic protector cap from marking pin for horizontal graph.

11

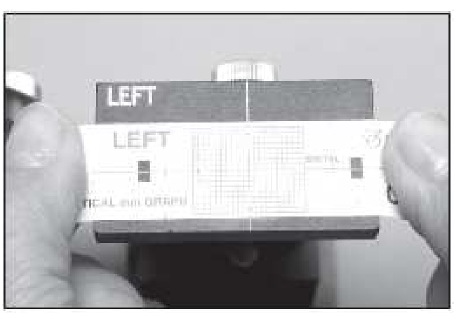


Place maxillary frame on right side graph support for placing left vertical graph paper. Note anterior end of frame resting on "foot" of transverse support post (arrow).

12

With small-ended dental instrument (e.g. Tanner carver), lift one end of vertical graph paper. Grasp free end of graph paper with thumb and index finger. Press tip of dental instrument against rectangular cut-outs on graph paper while slowly peeling adhesive coated paper from backing sheet. (Two small rectangular cut-outs should remain attached to backing sheet after graph paper has been removed.)

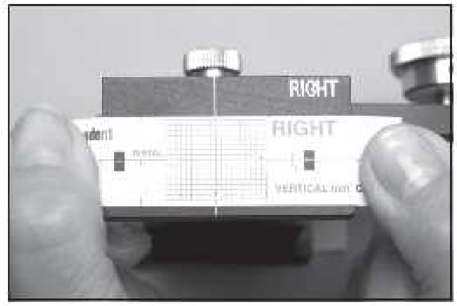
13



Hold both ends of graph paper with thumbs and index fingers. Brace index fingers against anterior and posterior ends of graph support and stretch paper tightly. Align both vertical and horizontal cross lines of paper with cross lines on graph support. After final alignment is complete, apply light finger pressure to adhere paper firmly to graph support.

14

Turn maxillary frame on left side and repeat procedure 12 - 13 for right side graph paper.



15

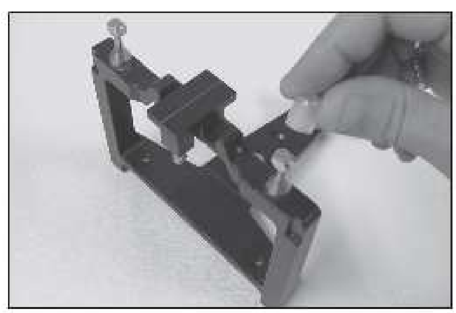
Attach interchangeable articulator mounted maxillary cast to upper frame of CPI with mounting plate thumbscrew (or magnetic mounting plate).

16

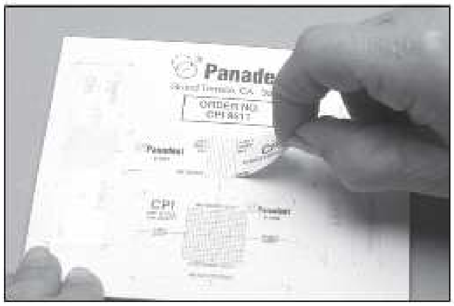
Loosen mounting plate thumbscrew and remove inter-frame support column from mandibular frame of CPI. Avoid binding column on precision dowel holes during removal.

17

Set mandibular frame upright with legs resting on a flat stable working surface in preparation for placing horizontal graph paper. Remove protective caps from both axis pointer elements.

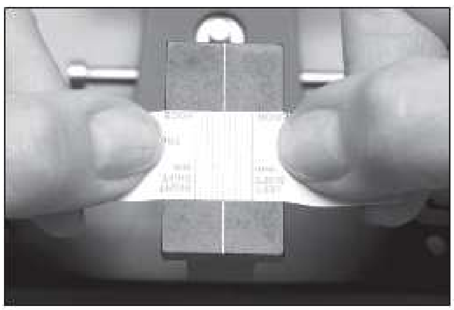


18



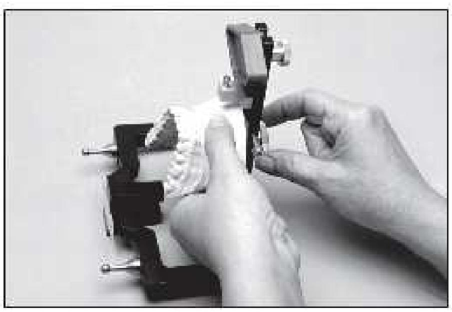
Lift one end of horizontal graph paper and peel it slowly from backing sheet.

19



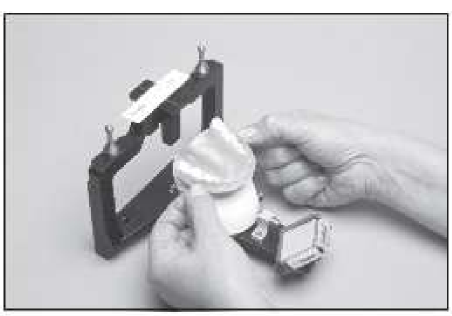
Stretch horizontal graph paper laterally with thumbs and index fingers. Align heavy center line of paper with center line of graph support. (Anterior-posterior position is not critical.)

20



Attach interchangeable articulator mounted mandibular cast to lower frame of CPI with mounting plate thumbscrew (or magnetic mounting plate).

21



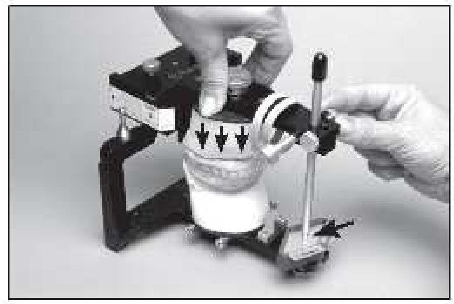
Place CR or M.I.P. interocclusal record (depending on the procedure) on mandibular cast.

Fit maxillary cast into interocclusal record. Press firmly downward on maxillary frame with one hand to keep casts completely seated in interocclusal record (arrows).

22

With other hand, loosen anterior support pin thumbscrew and allow support pin to drop down freely until end of pin makes solid contact with *Incisal Table* (horizontal arrow). Lock support pin firmly in down position with thumbscrew.

Note: *If support pin falls too near distal end of support table, support pin can be placed in the anterior pin hole on maxillary frame.*



23

Place two elastic support bands over maxillary mounting plate thumbscrew. Have one elastic support band hanging to right side and one to left side of maxillary cast.

24

While pressing firmly downward on maxillary frame with one hand (top vertical arrow), use index finger and thumb of other hand to spread and stretch one elastic support band down and over both retainer pins protruding horizontally from side of mandibular frame below mandibular cast (bottom arrows).

25

26

Continue downward hand pressure on maxillary frame after first elastic support band has been placed. Place opposite side elastic support band over retaining pins with thumb and index finger in same manner as other side.

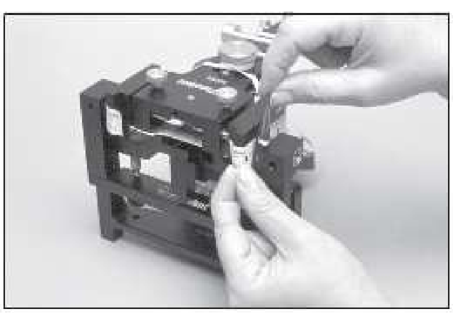
27

Remove hands. Supported assembly holds position.

28

Loosen locking thumbscrew for vertical graph support in preparation for marking vertical graph.

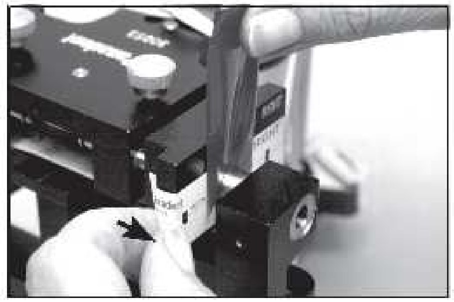
29



Place single sided marking ribbon over graph paper (dye toward paper) with fingers of one hand. Grasp <u>distal end</u> of graph support with thumb and index finger of other hand for marking graph paper.

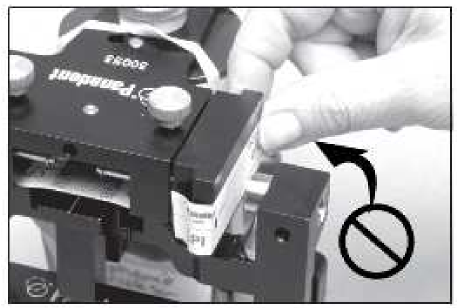
Pull laterally on distal end of graph support (arrow) to bring graph paper in contact with axis pointer.

Warning: *Do not use excess force when marking graph. Excess pressure will cause sharp point of axis pointer to penetrate paper, scratching anodized surface of graph support and also dulling tips of pointer.*



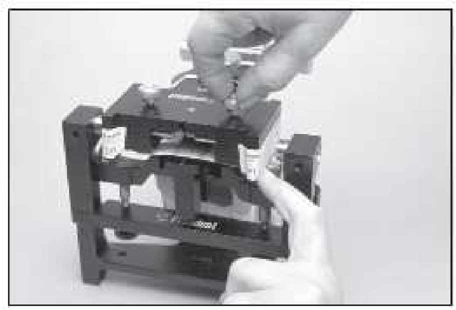
30

⊘ Do not pull or push on anterior end of graph support to mark graph paper as support may bind.



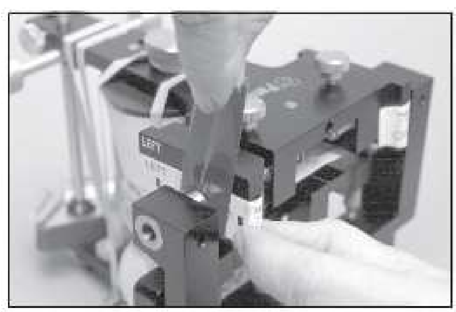
31

After marking graph paper, lock graph support in contact with side of maxillary frame with thumbscrew.



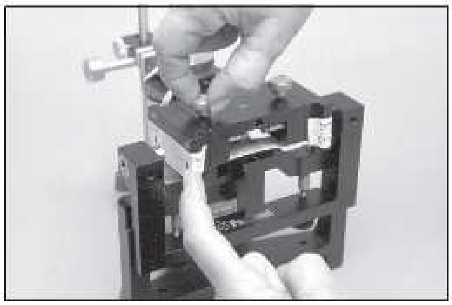
32

Repeat procedures 28-31 to mark axis on opposite side vertical graph paper in same fashion as other side.



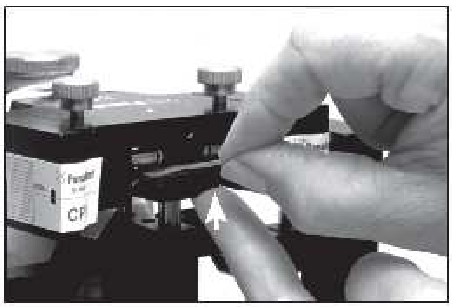
33

34



Lock graph support in contact with maxillary frame.

35



Place marking ribbon (dye toward graph paper) with index finger and thumb of one hand. Mark horizontal graph by lifting up on distal end of graph support with index finger of other hand (vertical arrow).

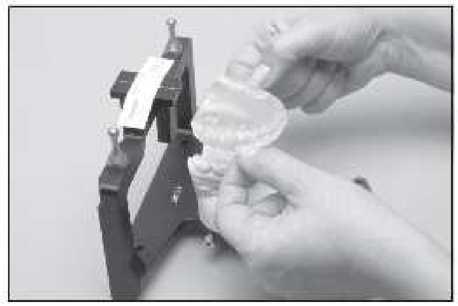
36

In preparation for removing casts from CPI, release and remove the two lateral elastic support bands from their associated retainer pins below mandibular cast.

37

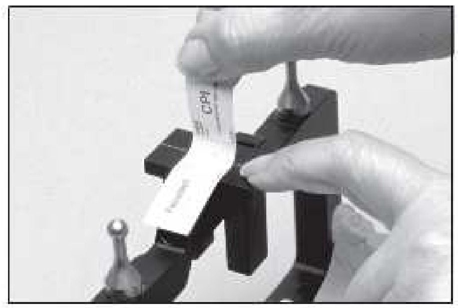
Hold mandibular frame firmly against working surface with one hand. Lift maxillary frame assembly <u>vertically</u> from mandibular frame assembly with other hand

Remove interocclusal record from mandibular cast.



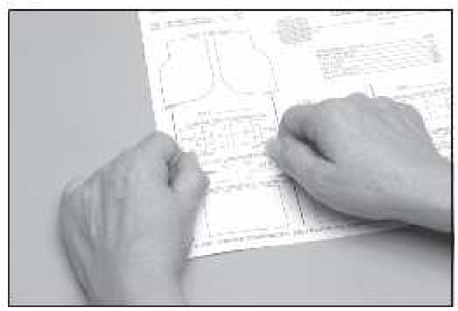
38

Hold horizontal graph support down with index finger of one hand. Peel graph paper slowly from graph support with thumb and finger of other hand.



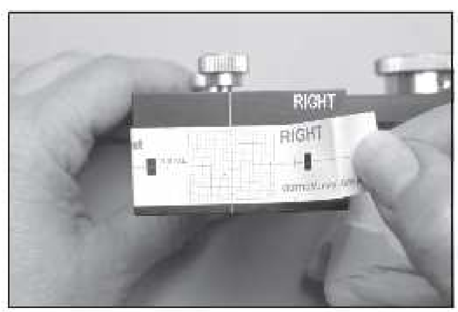
39

Place horizontal graph paper to patient data record sheet via self-adhesive backing on graph paper.



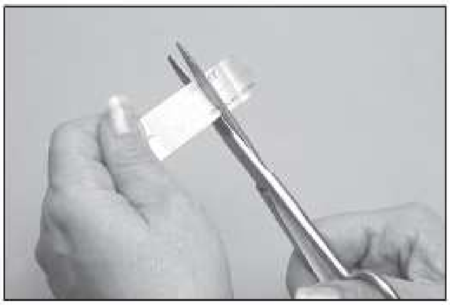
40

Remove vertical graph papers from maxillary frame by peeling paper slowly away from graph supports.



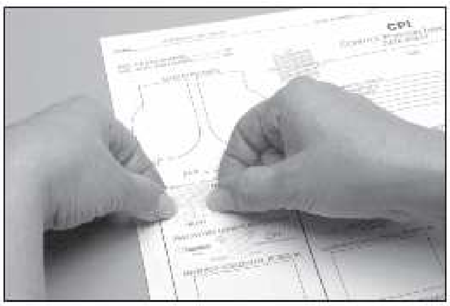
41

42



Shorten graph papers by cutting ends at vertical tick lines on either side of millimeter grid.

43

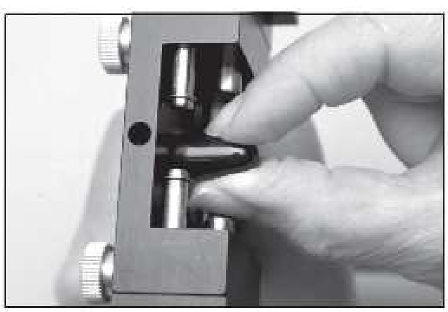


Place vertical graph papers to patient's data record sheet via self-adhesive backing on graph papers.

44

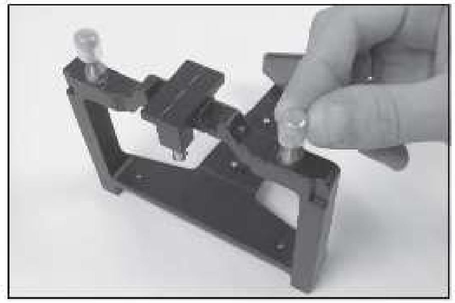
OPTIONAL: Use optical resolver (10x) and illuminator to read graph markings accurately with 0.1mm reticle scale in resolver.

45



Press protector cap completely over horizontal graph marking pin.

Press protective cap completely over both axis pointer elements.



46

For storage of CPI, reattach maxillary and mandibular frames to inter-frame support column. Lock both vertical graph supports in contact with maxillary frame.

47

For technical support call (909) 783-1841

Degree of Accuracy: within .1mm

Ⓢ 9611: If used more than one time, it will no longer adhere to surface.

Ⓢ 9615: If used more than one time, paper may be torn and therefore unusable.