Investigating the effect of skeletal pattern in determining articulator settings for prosthodontic rehabilitation: An *In-vivo study.*

Lead Investigator: Dr. Thomas G Canning BDentSc MFD(RCSI)

Supervisor: Dr. Michael O'Sullivan BDentSc PhD

Submitted in part fulfilment DChDent (Prosthodontics) University of Dublin. 2008.

Declaration

I hereby declare that this thesis had not previously been submitted for a degree at this or any other university and that it represents my own work except where duly acknowledged in the text.

I hereby agree that the library may copy or lend this thesis upon request.

Signed: Tom Canning

Date: 16/12/08

Acknowledgements

I would like to thank my family for their continuing support and encouragement.

Also I would like to thank my clinical supervisors, Professor Brian O'Connell, Frank Houston, Gerry Cleary, Colm Sugrue, Anne Gunderman and Brendan Grufferty. Their advice throughout the project was invaluable.

A large debt of gratitude is owed to my project supervisor, Dr. Michael O'Sullivan for his patience and assistance throughout.

This work is dedicated to my wife Naoishe.

Table of Contents

Table of Figures

Table of Tables

Summary

During extensive prosthodontic treatment the use of an accurately adjusted articulator is recommended to simulate some mandibular movements.

An *in-vivo* clinical study was undertaken to assess any possible effect of underlying skeletal pattern on articulator settings.

Subjects were recruited (N=73) from a dental school and two regional orthodontic units. A clinical examination was undertaken where the participants were screened for functional problems of the masticatory system. The presence of dysfunction resulted in subjects being excluded from the study.

A profile photograph was taken of each subject with their teeth in maximum intercuspation with the Frankfort plane horizontal. Subjects were allocated into study groups based on their underlying sagittal and vertical skeletal pattern. Profile photographs of subjects using a fixed focal lenght were used as a means of assessing skeletal characteristics.

Electronic pantographic recordings were made with the Cadiax® Compact system and recorded on a personal computer.

Subjects were assigned to study groups on the basis their underlying sagittal and vertical skeletal pattern. A slide show was created of all the profile photographs. Senior staff from the Dublin Dental School and Hospital were shown this and categorised each subject according to their sagittal and vertical skeletal pattern.

The articulator settings obtained from the pantographic recordings were grouped according to study group. Six study groups were recognised, sagittal I, sagittal II, sagittal III, reduced vertical, average vertical and increased vertical.

The data were examined statistically on the basis of sagittal and vertical categories.

The Sagittal Condylar Inclination measurements, Transverse Horizontal Guidance measurements, Immediate Side Shift and reproducibility of the reference position were compared between groups. In addition, testing was undertaken to determine the reliability of assessment of profile photographs in sagittal and vertical skeletal pattern classification.

Results

Agreement between individuals for sagittal skeletal pattern classification was excellent. Agreement between individuals for vertical skeletal pattern was high, but at a lower level than for sagittal relationships.

Sagittal Condylar Inclination settings for sagittal II subjects were significantly higher than those for skeletal I ($p<0.05$) and sagittal III ($p<0.001$) subjects. No statistical difference could be observed between the Sagittal Condylar Inclination values of the sagittal I and sagittal III groups. Subjects with an average vertical skeletal pattern had Sagittal Condylar Inclination values lower than those with a reduced vertical skeletal pattern ($p=0.058$) and significantly lower than subjects with an increased ($p<0.01$) vertical skeletal pattern.

No differences could be observed for Transverse Horizontal Guidance, Immediate Side Shift, or reference position reproducibility between the study groups. The majority of the sample population had Immediate Side Shift settings of 0mm, with the remaining values ranging from 0.1 mm to 1mm. Values greater than the threshold of 0.5mm were rarely seen. The Transverse Horizontal Guidance measurements for all study groups clustered at the minimum value (5°) and to a lesser extent the maximum (15°). For all study groups the reference position was observed to be reproducible with isolated exceptions in all groups.

Conclusion.

Assessment of underlying skeletal pattern from profile photographs appears to be reliable between individuals. Agreement for sagittal classification of skeletal pattern is greater than for vertical classification.

During extensive prosthodontic treatment of patients with a noticeable skeletal discrepancy consideration should be given to Sagittal Condylar Inclination values.

Due to the distribution of data for the Transverse Horizontal Guidance measurements no conclusions or recommendations could be made regarding the effect of skeletal pattern on these articulator settings. Similarly, no recommendations could be made regarding reference position reproducibility or Immediate Side Shift values on the basis of skeletal pattern.

From the observed data all study groups demonstrated good reproducibility of the reference position.

Immediate Side Shift values for all study groups were low and clustered around zero.

1. Abstract

Statement of Problem.

During extensive prosthodontic treatment the use of an accurately adjusted articulator is recommended to simulate some mandibular movements.

Purpose.

An *in-vivo* clinical study was undertaken to assess any possible effect of underlying skeletal pattern on articulator settings.

Materials and methods.

Subjects were recruited (N=73) from a dental school and two regional orthodontic units. Electronic pantographic recordings were made with the Cadiax® Compact system. Subjects were allocated into study groups based on their underlying sagittal and vertical skeletal pattern. Profile photographs of subjects were used as a means of assessing skeletal characteristics. Photographs were assessed by a group consisting of three orthodontists and three prosthodontists.

Results.

Agreement between individuals for sagittal skeletal pattern classification was excellent. Agreement between individuals for vertical skeletal pattern was high, but at a lower level than for sagittal relationships. Sagittal Condylar Inclination settings for sagittal II subjects were significantly higher than those for sagittal I ($p<0.05$) and sagittal III ($p<0.001$) subjects. No statistical difference could be observed between the Sagittal Condylar Inclination values of the sagittal I and sagittal III groups. Subjects with an average vertical skeletal pattern had Sagittal Condylar Inclination values lower than those with a reduced

vertical skeletal pattern ($p=0.058$) and significantly lower than subjects with an increased ($p<0.01$) vertical skeletal pattern. No differences could be observed for Transverse Horizontal Guidance, Immediate Side Shift, or reference position reproducibility between the study groups. The majority of the sample population had Immediate Side Shift settings of 0mm, with the remaining values ranging from 0.1 mm to 1mm. Values greater than the threshold of 0.5mm were rarely seen. The Transverse Horizontal Guidance measurements for all study groups clustered at the minimum value (5°) and to a lesser extent the maximum (15°). For all study groups the reference position was observed to be reproducible with isolated exceptions in all groups.

Conclusion.

During extensive prosthodontic treatment of patients with a noticeable skeletal discrepancy consideration should be given to Sagittal Condylar Inclination values.

2. Introduction

Traditional prosthodontic teaching has advocated the use of articulators as a means of simulating mandibular movement during the fabrication of indirect dental restorations.[1] Numerous such devices have been introduced to the dental profession to this end and many of these have been recommended for use depending on the particular scenario the clinician is confronted with.[2] The design of these instruments differs greatly in many cases depending upon the individual philosophy to which it may be applied. Many are based upon average anatomical values from observational experimentation.[3, 4] In managing a patient with prosthodontic requirements the dentist has the option of using the articulator set to its average values or alternatively setting the articulator to more faithfully reproduce the movements of that individual.[5] Methods commonly used to obtain individual condylar settings are listed in table 3.5.

Many authors believe that the skeletal pattern may have an association with the condyle and fossa morphology of the TMJ.[6-18] The orthodontic literature has pointed to a possible interaction between facial characteristics/skeletal morphology and mandibular movement or function.[19-24]

Orthodontic patients may be classified according to their sagittal or vertical skeletal pattern. The aim of this study was to use an electronic pantograph to determine the possible influence of underlying skeletal pattern upon mandibular movement and resultant articulator settings.

Throughout the past decades there has been much disagreement between authors regarding terms and/or definitions in the field of fixed and removable prosthodontics. This has led to much undue confusion, particularly in the study of occlusion and mandibular movement. Listed below is a glossary of terms used in this research, commonly used alternatives are added to aid the reader in understanding their intended meaning.

2.1 Glossary of terms used in this study.

Abbreviation	Definition	Alternative Term
MIP	Maximum Intercuspal Position	Maximum Intercuspation, Centric Occlusion
CR	Centric Relation	Retruded position
Frankfort Plane	Line extending from the superior aspect of the bony external auditory meatus to the inferior border of the orbit.	Frankfort horizontal
Sagittal skeletal pattern	Orthodontic classification. Refers to the anteroposterior relationship of the mandible to the maxilla when viewed sagittaly.	
Pantographic recording	A graphic record of mandibular movement usually recorded in the horizontal, sagittal and frontal planes as registered by styli on	Pantographic tracing

	the recording tables of a pantograph or by means of electronic sensors	
Axiographic recording	No definition exists, however, in general use refers to a recording of mandibular movement in relation to change in position of the transverse horizontal axis	Axiographic tracing
Vertical skeletal pattern	Orthodontic classification.	
Sagittal I skeletal pattern	Maxilla lies approx 2-3mm anterior to mandible viewed sagittaly.	Orthognathic
Sagittal II skeletal pattern	Maxilla prominent in relation to class I position.	Retrognathic
Sagittal III skeletal pattern	Mandible prominent in relation to class I position.	Prognathic
Reduced vertical skeletal pattern	Skeletal classification where the lower face height is reduced in comparison to the	Hypodivergent

	upper face height.	
Average vertical skeletal pattern	Skeletal pattern where the lower face height is judged to be in correct proportion to the upper face height.	
Increased Vertical skeletal pattern	Skeletal classification where the lower face height is increased in comparison to the upper face height.	Hyperdivergent
Sagittal Condylar Inclination(SCI)	Articulator setting, the angle formed between the condylar element of the articulator and the reference plane in the sagittal plane.	Protrusive condylar path, protrusive path, condylar inclination, condylar path, protrusive condylar inclination
Transverse Horizontal Guidance(THG)	Articulator setting. Measures the medial pathway of the non-working side condyle during a lateral movement.	Progressive side shift, progressive mandibular lateral translation, Bennett Angle.
Immediate Side Shift	Articulator setting. Measures a bodily shift of the non-working condyle at the beginning of a	Immediate mandibular lateral translation

	lateral movement.	
Reference position *Used in this study	The position from which all mandibular movements originated and terminated. Subjects rested with the mandibular clutch close to but not touching their maxillary teeth.	
Bracycephalic	Facial type. Characterised by a short and wide facial form.	
Doliocephalic	Facial type. Characterised by a long and thin facial form.	
Mutually protected occlusal scheme	Concept of occlusion whereby the posterior teeth are protected from interferences by the canine teeth in lateral movements and the anterior teeth in protrusive movements.	Canine Guidance
Progressive side shift	Articulator setting. Measures the medial	Progressive mandibular lateral

	pathway of the non-working side condyle during a lateral movement.	translation, Transverse Horizontal Guidance.
Orbiting path	Articulator setting. Measures the pathway of the non-working condyle.	
Kinematic hinge axis	Transverse horizontal axis of mandibular movement located through observation of an individual's condyle rotating in centric relation.	Kinematic transverse horizontal hinge axis
Arbitrary hinge axis	Transverse horizontal axis of mandibular movement located through average measurements.	Arbitrary transverse horizontal hinge axis
Left mediotrusion	Mandibular movement. Describes a right lateral movement of the mandible.	Right lateral excursion
Right mediotrusion	Mandibular movement. Describes a left lateral movement of	Left lateral excursion

	the mandible.	
Condylotrack distance	Relates to the distance travelled by the condyle during a mandibular movement.	
THA	Transverse axis passing through both condyles, about which pure rotation can theoretically occur.	Transverse horizontal axis
Working side	The side towards which the mandible moves during a lateral movement.	
Balancing side	The side from which the mandible moves away during a lateral movement.	Non-working side
Articular eminence inclination	The steepness of the slope of the articular eminence. Measured from Frankfort plane or the occlusal plane.	
Anterior open bite (AOB)	Incisal relationship where there is a negative vertical overlap between the maxillary and	

	mandibular teeth.	
Condylar Position Measurement (CPM)	Cadiax®Compact function which measures the average deviation of a recorded position from the previously recorded reference position.	

Table 2-1 Glossary of terms used in study.

3. Literature Review

3.1 Anatomy of the Temporomandibular Joint

The osseous structures of the TMJ consist of the condylar process of the mandible and the glenoid fossa and the glenoid eminence, parts of the squamous portion of the temporal bone. The glenoid eminence is convex anteroposteriorly and concave mediolaterally. Its shape corresponds generally to that of the articular part of the condylar process. The function of the articular eminence is to provide an inclined plane which can direct the anteriorly moving condyle downwards. On the medial aspect lies the medial glenoid plane and this provides a guiding ridge to the movement of the condyle during lateral movements of the mandible.

The shape of the glenoid fossa corresponds generally to that of the articular part of the condylar process of the mandible. It should be noted that the condyle only approximately fits within the fossa. The intervening area is taken up by the articular disc, a biconcave structure, in a healthy joint. The articular disc of the temporomandibular joint is attached to the condyle (anteriorly, posteriorly, medially and laterally), the preglenoid plane, the joint capsule, the posterior wall of the glenoid fossa, the middle ear and the superior head of the lateral pterygoid muscle.[25]

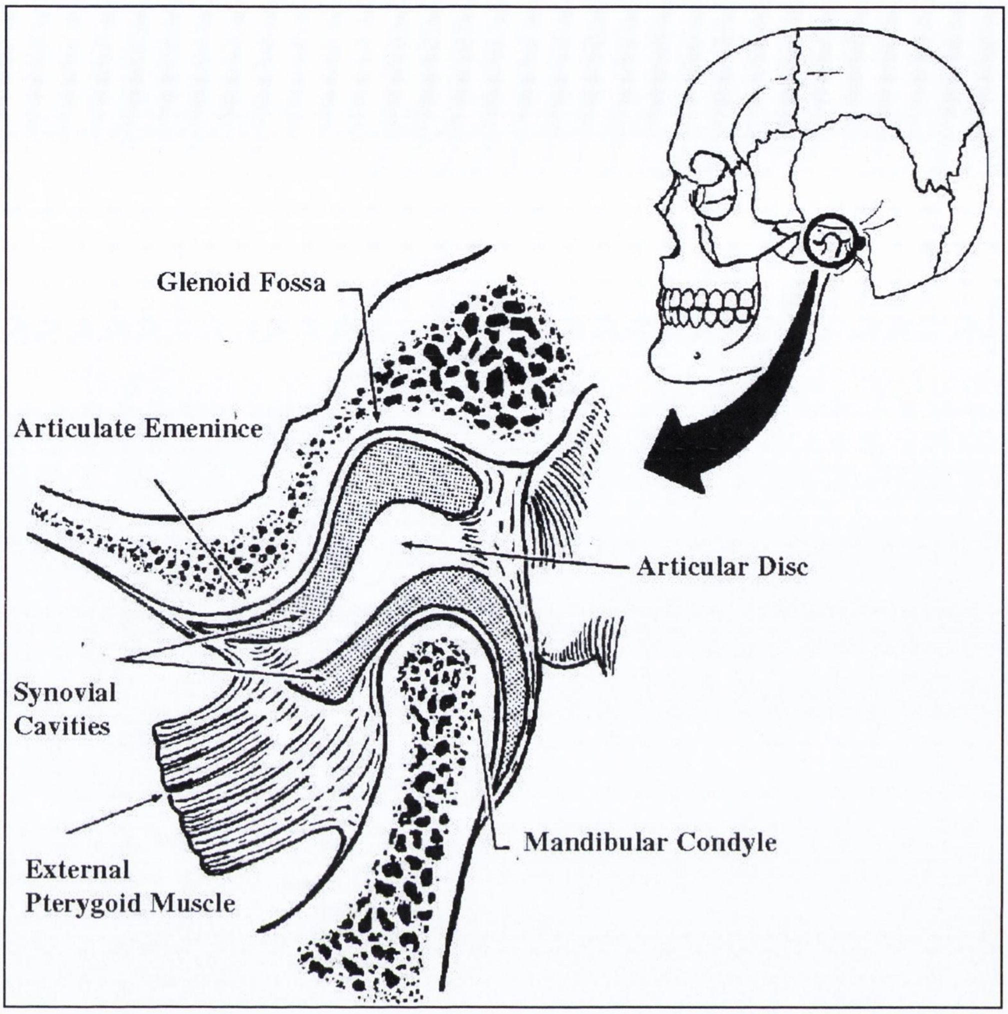


Figure 3-1 Anatomy of the Temporomandibular joint.[26]

The superior and inferior heads of the lateral pterygoid muscle have attachments to the articular disc, and the anterior aspect of the condyle respectively.[27] Upon function they act to move the condyle/disc assembly forwards and downwards along the articular eminence. When the elevators of the mandible act to reposition the mandible in the glenoid fossa tension in these muscles helps to stabilise the condyle/disc relationship.

3.2 Classification, diagnosis and prevalence of orthodontic skeletal malocclusion.

Orthodontic classification systems are an aid to describing a malocclusion by its characteristic features. Many such systems are in existence and they contribute to recording the prevalence of a particular malocclusion in a population, while also assessing the need for, the difficulty and the success of orthodontic treatment.[28]

Two of the most universally accepted classification systems are Angle's Classification and the British Standards Institute Classification. Angle was of the belief that the position of the permanent first molars was constant in relation to the facial skeleton and that this could serve as a reference for the relative anteroposterior positioning of the dental arches.[29] While this assumption was incorrect the classification still is widely used to describe the molar relationship in orthodontic patients.[30] The British Standards Institute classification[31] describes the position of the mandibular incisors relative to the maxillary incisors.

Contemporary orthodontic diagnosis arrives at a problem list of the individual's characteristic malocclusion. It is widely accepted that many malocclusions are multifactorial in origin and that there are genetic, skeletal, dentoalveolar, functional and environmental factors at play. From a skeletal standpoint orthodontic malocclusions are characterised as Class I, Class II and Class III. A vertical component to skeletal pattern is also recognised.[32] Numerous cephalometric analyses have been advocated to help determine the anteroposterior skeletal pattern.

I. ANB Angle[33]. This relies on the cranial base (SN) as a reference from which to determine the relative anteroposterior position of the maxilla and mandible.
   ANB $< 2°$ Class I

2°<ANB<4° Class II

ANB > 4° Class III

II. Ballard conversion. This relies upon making a cephalometric tracing and adjusting the angulation of the maxillary and mandibular incisors to the maxillary and mandibular planes respectively. This essentially reverses any dentoalveolar compensation which may be present and the true anteroposterior relationship of the mandible to the maxilla should be apparent.

III. Wits Analysis[34]. This compares the A and B points to the functional occlusal plane. Perpendicular lines drawn from the functional occlusal plane to these maxillary and mandibular landmarks are used to ascertain the anteroposterior relationship.

Cephalometric analyses should be considered as diagnostic tools and differences in certain values should not be used rigidly as criteria for treatment. Deviation from the population average for a given measurement may be compensated for elsewhere in the facial skeleton.

The anteroposterior skeletal pattern can also be assessed by viewing the patient in profile. The following classification is universally recognised.[35]

Class I: The mandible is 2-3mm posterior to the maxilla

Class II: The mandible is retruded relative to the maxilla

Class III: The mandible is protruded relative to the maxilla

Proffit [36] noted that contemporary orthodontics relies on the use of cephalometric radiographs for determining facial proportions. Prior to their introduction anthropometric measurements were commonplace. Recently such measurements have undergone a revival following the work of Farkas[37] and this understanding is now being used in the management of growing patients with cleft palate and other dentofacial developmental defects.

Proffit suggests the following approach to facial analysis.

The patient should be observed standing looking at the horizon to ensure the Frankfort plane is horizontal. Two lines must then be constructed, one from the bridge of the nose to the base of the upper lip and another from the base of the upper lip to the chin. Where these 2 lines are straight the anteroposterior relationship can be considered normal. Where a convex profile is observed this indicates a skeletal II pattern. A concave profile suggests a skeletal class III relationship.

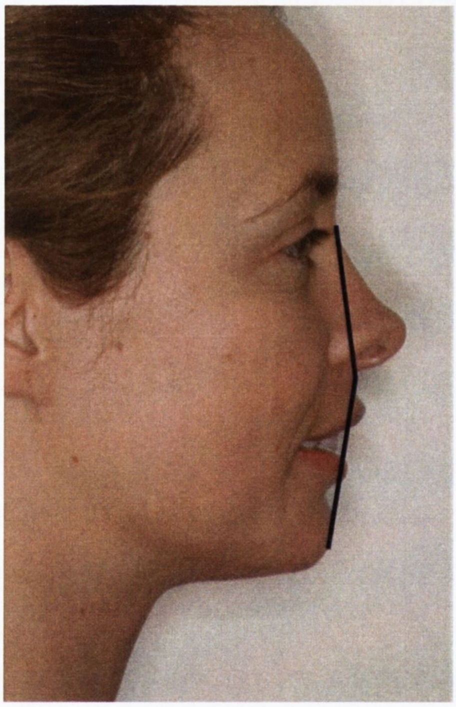


Figure 3-2 Class II Subject demonstrating convex facial profile.

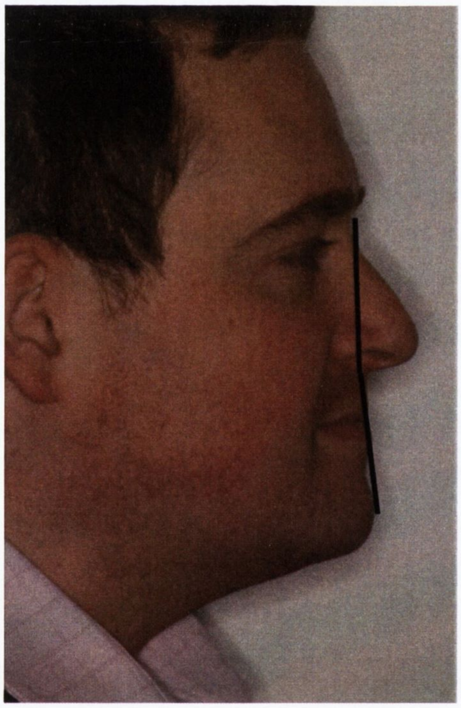


Figure 3-3 Class III Subject demonstrating concave facial profile.

Commonly encountered orthodontic malocclusions include Class II division 1, Class II division 2 and Class III. Class II division 1 malocclusions are usually associated with an underlying class II skeletal pattern which is generally a result of a retrognathic mandible. The prevalence of Class II division 1 malocclusions is thought to be between 15-20% in a Caucasian population.[38]

Class II division 2 are estimated to be present in approximately 10% of a Caucasian population. It may be associated with a mild class II skeletal pattern or in some cases a skeletal I or mild skeletal III pattern can be observed.[39] Class III malocclusions are the least common observed in a Caucasian population, with an estimated prevalence of approximately 3%. The skeletal relationship is considered to be the most important factor in the etiology of this type of malocclusion.[40] A class III skeletal pattern may result from either a relatively retrusive maxilla, a prognathic mandible or a combination of both.

Proffit [41] reported on the NHANES III survey in 1998 and reported that in the US 57-59% of each racial/ethnic group had at least some orthodontic treatment need. Among American children and youths Class I malocclusions were the most prevalent accounting for 50-55%, Class II malocclusions accounted for approximately 15 % while Class II malocclusions were only evident in 1%. It has been observed that the spectrum of malocclusions is not the same in different countries and racial groups experience different distributions of malocclusion.[42] Class II malocclusions appear to have a higher frequency in Northern European populations (approximately 25% in Denmark) while Class III malocclusions are more common in Asian countries (5% in China and Japan).

In recent times a paradigm shift has occurred which has seen the emphasis shifting somewhat away from skeletal and dental relationships only. Currently a greater consideration is being directed towards dentofacial aesthetics and the soft tissue profiles of the oral and facial structures.[36] The emphasis has moved from strict application of orthodontic norms and a reliance on orthodontic tooth movement to a broader approach encompassing dentofacial growth modification and orthognathic surgery when appropriate.

3.3 Relationship between skeletal pattern/malocclusion and mandibular condyle and articular eminence morphology.

The articular eminence of the temporal bone is generally not well developed at birth. Its inclination increases rapidly with the eruption of the primary dentition and it has reached approximately half of its adult size by 2 years of age. The eminence inclination continues to grow and at 20 years it has reached approximately 95% of its final size. [43]

Many authors [6-17] have discussed possible correlations between skeletal patterns and the shape, size and morphology of the articular eminence and mandibular condyle. There is some confusion about the relationships between the condyle/fossa morphology and certain skeletal or facial characteristics. The conflicting results from these studies may be due in part to differing methods of measurement and from the use of a range of clinical or radiographic criteria to facilitate assessment of the skeletal relationship. Methods which have been used to measure the articular eminence inclination of the TMJ include modelling clay impressions, direct measurements, panoramic and tomographic (corrected and uncorrected) radiographs, arthrograms, lateral cephalometric radiographs, photography, protrusive condylar paths and wax patterns of dried skulls.[43] The methods used have an influence on the resultant values for eminence angulation as each method has its own advantages and disadvantages. Measurement of the protrusive condylar path can provide a non-invasive indirect measurement of the eminence angulation.[44]

While there has been much investigation into a possible relationship between the skeletal pattern/facial morphology and the TMJ condyle and fossa morphology no absolute agreement has yet been reached.

Author	Study Method	Study Population	Country of Origin	Findings
Ricketts 1953[6]	Laminography	Caucasian orthodontic patients		Angle Class III malocclusion: shallower glenoid fossa and flatter articular eminence than Class I and Class II.
Ingervall 1974[7]	Profile radiographs	Swedish adolescents/adults	Sweden	Increased height of the articular eminence was observed in those patients with a rectangular face form, an increased posterior face height and mandibular prognathism
Pullinger et al. 1987[8]	TMJ Tomograms	Dental students	USA/Sweden	Class II division 1 malocclusions exhibited a more anteriorly positioned condyle than did Class I subjects
Widman 1988[9]	Axiographic tracings superimposed on lateral Cephalometric radiographs	Orthodontically treated adolescents/young adults	USA	Bracycephalic (short and wide) facial types: vertical inclination of the articular eminence. Doliocephalic facial types: more shallow articular eminence angle.
Giannelly et al. 1989[10]	Corrected tomograms	Orthodontic patients	USA	No significant correlation between condylar position and vertical overlap
Seren et al. 1994[11]	Axial Computerised Tomography	Adult orthodontic patients	Turkey	Class III: smaller anterior joint spaces consistent with mandibular prognathism. Glenoid fossa was smaller in an AP direction compared with Class I.
Cohlmia et al. 1996[12]	Lateral cephalometric radiographs and corrected tomograms	Orthodontic patients of Caucasian descent	USA	The condyles of patients with a class III malocclusion were positioned

				significantly more anteriorly. A shallower articular fossa and flatter articular eminence slope was also observed in the class III group
Ikai et al. 1997[13]	Anthropological measurements	Dry skull specimens	Japan	Inverse relationship between the angle of the articular eminence to the Frankfort horizontal plane and the ANB angle.
Burke et al. 1998[14]	Lateral cephalometric radiographs and corrected tomograms	Adolescents with Class II malocclusion	Canada	Condylar head inclination and superior joint space appeared to be significantly related to the patients' facial morphology
Akahane et al. 2001[15]	Lateral cephalometric radiographs and laminographs	Adult females with Class I & Class III occlusion	Japan	Class III: significantly shallower articular eminence angle and larger superior joint spaces compared to Class I controls.
Kikuchi et al. 2003[16]	Lateral cephalometric radiographs and corrected tomograms	Adolescent orthodontic patients	Japan	condyle positioned more posteriorly in the glenoid fossa in cases demonstrating a clockwise rotation of the mandible
Katsavrias & Halazonetis 2005[17]	Corrected tomograms. Procrustes superimposition morphometric analysis.	Orthodontic patients	Greece	Class III: condyle observed to be more elongated and inclined forward, the fossa was wider and shallower. Condyle located closer to the roof of the fossa in Class III patients.
Katsavrias 2006[18]	Corrected lateral tomograms	Wide age range, Class II division 2 malocclusions.	Greece	There was great variation between articular eminence and mandibular ramus morphology.

Table 3-1 Relationship between malocclusion and condyle/fossa morphology.

Ricketts[6] in 1953 noted that subjects with a Angle Class III malocclusion demonstrated a shallower glenoid fossa and a flatter articular eminence in comparison Class I and Class II subjects. Furthermore he noted that there was no significant difference between the TMJ fossa/eminence between Class I and Class II patients.

Ingervall[7] attempted to examine the possible relationship between the height of the articular eminence and subsequent path of the condyle and facial morphology. Patients were examined using profile roentgenograms taken with the subjects in MIP, at 5mm protrusion, maximum protrusion and maximum opening. This study concluded that a marked condylar path inclination and increased height of the articular eminence was observed in those patients with a rectangular face form, an increased posterior face height and mandibular prognathism. Conversely, a triangular facial form, reduced posterior face height and mandibular retrognathism appeared to be associated with a shallower and smaller articular eminence.

The position of the condyle within the articular fossa has also been examined. Pullinger[8] observed TMJ tomograms of 44 adults who had no history of occlusal or orthodontic therapy and demonstrated healthy asymptomatic joints. The aim of this investigation was to examine the influence of occlusion on the condylar position within the TMJ. The author concluded that at MIP a non-concentric condylar position was a feature of Class II malocclusions. Class II division 1 malocclusions exhibited a more anteriorly positioned condyle than did Class I subjects. It should be noted however that this study only observed thirty Class I patients, ten Class II division 1 patients, two Class II division 2 patients and two Class III patients. Whether there are differing positions of the condyle in a class III malocclusion was difficult to observe with such small numbers.

As has been mentioned numerous methods have been used in attempting to quantify and qualify condyle and fossa shape and morphology. Widman[9] attempted to establish if there was a relationship between the articular eminence inclination as measured from a lateral cephalometric radiograph and the angle observed from an axiographic tracing. Fifty orthodontically treated patients had their hinge axes and infraorbital points located and a

SAM II axiographic recording was made of the protrusive pathway. These points were radiographically marked and cephalometric radiographs exposed. An overlay technique was used for comparison. A marked correlation was observed between the radiographic eminence and the protrusive pathway suggesting that the condyle closely follows the contour of the articular eminence during protrusion. The author also noted that there was an inverse relationship between both the occlusal plane angulation and the mandibular plane angle, and the slope of the articular eminence. In summarising his findings Widman stated that bracycephalic (short and wide) facial types would tend to have a more vertical inclination of the articular eminence. In contrast doliocephalic (long and thin) facial types tended to have a more shallow articular eminence angle.

The position of the mandibular condyle within the TMJ has also been investigated with respect to the degree of vertical overlap present. Some authors have suggested that in cases of a deep vertical overlap, particularly in Class II division 2 cases, the condyle may be driven posteriorly and that this may contribute to TMJ symptoms. Giannelly[10] attempted to investigate this. Patients demonstrating a class II deep bite malocclusion (increased vertical overlap) with no overjet were compared with a control group of class II patients with normal overbite and >1mm overjet. In both groups the condyle was found to be concentrically located within the fossa. There was no significant correlation between the condylar position and the vertical overlap.

Seren[11] in 1994 used more sophisticated technology than had previously been utilised. Computerised tomography was used to investigate the condylar position within the glenoid fossa of untreated adults with a class III malocclusion. The Class III subjects were compared to CT images of a control group consisting of orthodontically normal patients. The following conclusions were made with regards to the Class III sample. A relative elongation of the mandibular condyle in a mediolateral direction was observed. Those with a class III malocclusion had smaller anterior joint spaces which would be consistent with mandibular prognathism and a forward positioned mandible. The glenoid fossa was smaller in an anteroposterior direction compared with the control group. No observations regarding eminence height or degree of eminence angulation were reported in this study.

An extensive investigation was undertaken by Cohlmia and colleagues[12] to investigate the morphologic relationship of the mandibular condyle and the glenoid fossa in patients with different malocclusions and skeletal relationships. Dental casts, hand wrist radiographs, lateral cephalometric radiographs and corrected tomograms of both left and right TMJs were evaluated. All subjects were of Caucasian descent. The authors concluded that there were no statistically significant differences observed regarding the position of the condyle in patients demonstrating Angle's Class I, End to End, Angle's Class II division 1 and 2 malocclusions. The condyles of patients with a class III malocclusion were positioned significantly more anteriorly. A shallower articular fossa and flatter articular eminence slope was also observed in the class III group, which is in agreement with Ricketts' earlier observations. Patients with high FMA (Frankfort to mandibular plane angle) measurements showed shallower glenoid fossae and flatter eminence slopes. The authors postulated that this may be related to shallower anterior guidance which is typically seen during protrusive movements in open bite cases and those with vertical growth patterns.

Anthropologic measurements have also been used in the quest to determine the relationship between condyle and fossa morphology and malocclusion. A group led by Ikai[13] made anthropologic craniometrical measurements on 33 Japanese dry skulls. This research showed an inverse relationship between the angle of the articular eminence to the Frankfort horizontal plane and the ANB angle. It was suggested that the steeper angle of the articular eminence may be related to a retrusive maxilla or a protrusive mandible.

Burke et al.[14] attempted to examine correlations between condylar characteristics and facial morphology in a group of Canadian Class II adolescents. Pre-orthodontic tomograms of 136 adolescents with class II malocclusions were studied. The condylar head inclination and the superior joint space appeared to be significantly related to the patients' facial morphology. Patients exhibiting vertical facial characteristics were associated with a decreased superior joint space and posteriorly angled condyles. Increased superior joint spaces were conversely correlated to patients having horizontal facial morphology. This study would suggest that decreased superior joint spaces were associated with Class II patients with a hyperdivergent tendency while an increased joint space was observed in Class II patients with a hypodivergent growth pattern.

Akahane[15] attempted to examine the TMJ morphology of patients with an Angles Class III malocclusion. Both symmetric and asymmetric Class III cases were studied along with a Class I control. All subjects were Japanese females who had not had orthodontic treatment and had asymptomatic TMJs. Radiographic examination was undertaken of both TMJs for each subject. Symmetric Class III patients demonstrated a significantly shallower articular eminence angle. Symmetric Class III individuals also demonstrated larger superior joint spaces when compared to the Class I control group. The group of asymmetric Class III patients did not show a significant difference in the articular eminence angulation, width of the glenoid fossa, height of the fossa, condylar width or superior joint space. The authors did however note that the position of the condyle on the shift side, the side to which the mandible was displaced in asymmetric cases, was located posteriorly and they believed that this may predispose such patients to anterior dislocation of the disc and clicking joints.

Kikuchi et al.[16] used tomograms and lateral cephalograms of 65 Japanese adolescents prior to orthodontic treatment to evaluate their condylar position and the condyle and fossa morphology. The aim was to investigate any relationship between condyle position and joint morphology and craniofacial morphology. The condyle was observed to be positioned anteriorly in the glenoid fossa but was centred mediolaterally. An inverse relationship was noted between the anterior joint space and the ANB angle. Similarly a negative correlation was seen with both the overjet and the gonial angle and the anterior joint space. The ramus plane angle showed a significant inverse relationship with the posterior, medial and lateral joint spaces. As a result of their findings the authors suggested that the condyle is more likely to be positioned more posteriorly in the glenoid fossa in cases demonstrating a clockwise rotation of the mandible.

The mandibular condyles and fossae of 47 Class II division2 subjects of different age ranges were examined using bilateral corrected lateral tomograms by Katsavrias in 2006.[18] This author reported that the condyle length and fossa morphology achieve their final sizes early in growth. There was great variation between articular eminence and mandibular ramus morphology. Features that were highly correlated to each other included, eminence height and eminence inclination, eminence height and ramus inclination, eminence inclination and ramus inclination and anteroposterior fossa dimensions. In this sample the predominant shape of the condyle and fossa was oval.

The same author in a previous article[17] presented data on a comparative study between the condyle and fossa shape in patients with Class II and Class III skeletal patterns. One hundred and eighty nine patients' axially corrected tomograms were subjected to morphometric analysis using a sophisticated method of Procrustes superimposition. Three groups were compared, Class II division 1, Class II division 2 and Class III. The Class III group was the only one to demonstrate a significant correlation between condyle and fossa size and age. This may point to continued growth at the TMJ at later stages in Class III patients. The condyle and fossa shape in the Class III group was found to be significantly different than that in either Class II group. The condyle of the Class III patients was observed to be more elongated and inclined forward and the fossa was wider and shallower. The condyle was located closer to the roof of the fossa in Class III patients. There were no statistically significant differences observed regarding the condyle and fossa morphology between the Class II division 1 and Class II division 2 patients.

3.4 Significance of anterior and posterior determinants of mandibular movement.

Movement of the mandible involves a complex interplay between the neuromuscular system, the temporomandibular joints and the teeth. The relative contributions of each remain unknown, however, in the healthy masticatory system these may be thought of as the determinants of mandibular movement. It is generally accepted that pattern generators at cerebral levels are involved in the control of the muscles driving the movement of the mandible.[45]

Students of mandibular movement attempt to simplify it by breaking it down into its component parts. Three axes of movement are described for each temporomandibular joint, vertical, saggital and horizontal. Mandibular movement is composed of rotation and translation. Rotation can occur about each of these axes. Translation of the mandible consists of a sliding movement of the condyle/disc assembly along the slope of the articular eminence[46]. An understanding of these basic principles is essential to the understanding of mandibular movement but it must be remembered that almost all functional movements of the mandible consist of simultaneous rotation around one or more of the axes and translation in a particular direction.

Early studies on mandibular movement noted that upon protrusion of the mandible there was an immediate separation of the posterior teeth. This resulted from a downward and forward movement of the mandibular condyle as it followed the curvature of the articular fossa. This has been described as the Christensen Phenomenon after Carl Christensen who first reported on it. Christensen suggested that an interocclusal wax protrusive record could be made and that by this means the pathway of the condyles recorded in an adjustable articulator.[47]

Luce[48] in his experimentation on mandibular movement used a mandibular facebow and described the condyles as moving downwards and forwards along a curved path. This was further demonstrated by pantographic tracings.

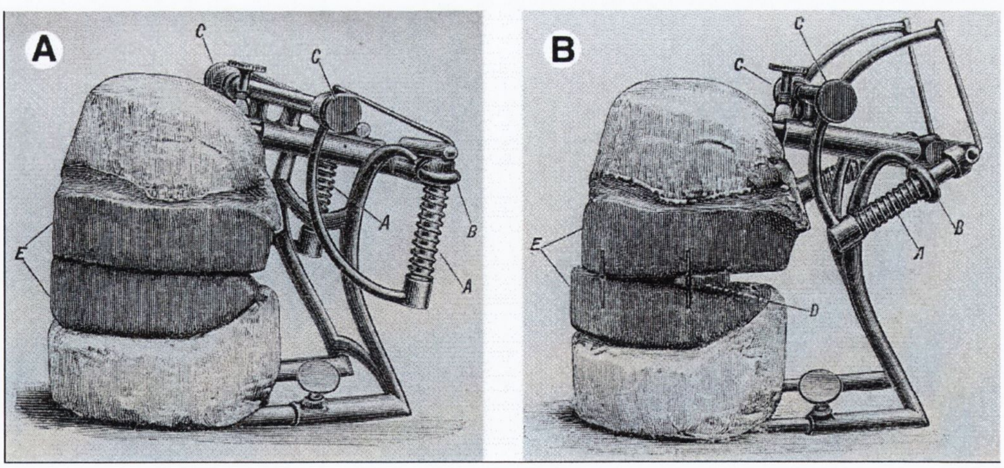


Figure 3-4 Christensen's articulator demonstrating protrusive wax record to set condylar inclination. From "The history of articulators: early attempts to reproduce mandibular movement, Part III: searching for the solution to a puzzle."[49]

The role of the anterior teeth has also been deemed important during mandibular movements. Observations of healthy natural dentitions have lead to the conclusion that the horizontal and vertical overlap relationships of the maxillary and mandibular anterior teeth also play a role in guiding mandibular movement.[50-52] The incisal edges of the mandibular anterior teeth glide along the palatal surfaces of the maxillary anterior teeth during protrusive and lateral movements of the mandible and in doing so provide disclusion of the posterior teeth. Such a relationship is termed a "*Mutually Protective Occlusal Scheme*" and has been suggested to offer the following advantages:[53]

- Prevention of potentially harmful working/non-working interferences
- Loading of posterior teeth along their vertical axis
- Protection of posterior restorations (particularly in the presence of ceramic occlusal surfaces which are known to be at risk of shear stresses
- Improved aesthetics
- Ease of fabrication and maintenance.

Historically there have been advocates of differing occlusal schemes ranging from bilateral balanced occlusal schemes to unilateral balance or group function to the canine guidance or mutually protected schemes. In the past the trend was to belong to one school of thought and attempt to rigidly apply all of its principals to each restorative case. There has been a gradual evolution towards the modern concept of a "Biologic Occlusion"[54]. This is a more flexible approach which may employ either a mutually protected or a group function occlusal scheme for lateral movements. The aim of a biologic or organic occlusion is to allow tooth guided mandibular movement either in protrusion or lateral excursion without the possibility of potentially damaging interferences.[55]

The relationship between the anterior guidance in a natural or restored dentition to that of the condylar guidance has been examined and a number of recommendations have been made. McHorris [56] suggested that the incisal guidance should be 5° steeper than that at the condyle, Shillingburg[57] makes the recommendation of 5-10°. Schuyler[58] recommends the eccentric movements are recorded in the patient and then the condylar inclination is reduced by 10° when the articulator is programmed. All authors are in agreement that the incisal guidance should be greater in value than that of the condylar guidance, a sentiment which is clearly stated by Lee[59]:

> "In no event should condyle movements be allowed to flatten the morphology of canines and premolars of artificial crowns when the occlusion is being treated."

There have been differing opinions in the literature regarding the association between the fossa inclination and the pathway taken by the condyle in protrusive and opening movements. Some investigators [52] have stated that the condyle closely follows the anatomical shape of the articular eminence. Others[60, 61] believe that there is more freedom within the TMJ and that the condyle can follow a protrusive path which may differ from the anatomical shape of the articular eminence. Corbett [44]using a combination of lateral cephalograms and axiographic recordings demonstrated a high correlation between the protrusive path of the mandibular condyle and the anatomic form of the articular eminence. This study would suggest that the condyle is closely approximated to the articular eminence and in protrusion its pathway is influenced by the slope of the eminence.

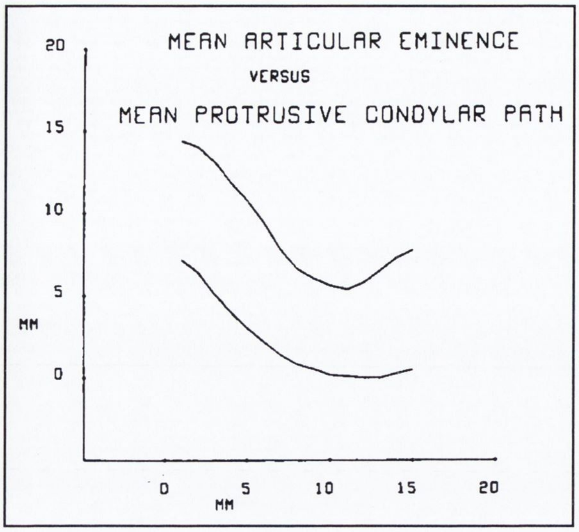


Figure 3-5 Graphical representation of data recorded by Corbett[44]demonstrating eminence and condylar path relationship.

Widman [9]attempted a similar study using a SAM II axiograph and lateral cephalograms. In this study the recorded angle of the protrusive path had a very high correlation (Correlation Coefficient 0.89) with the slope of the articular eminence as measured radiographically.

Gnathological concepts of occlusion favour incisal guidance as a means of providing posterior disclusion during mandibular movement. It is generally accepted that the angle of incisal guidance is steeper than the condylar guidance or articular eminence angle.[57] Bell and Harris[62] attempted to investigate the relationship between the incisal guidance angle and the articular eminence angle in a series of patients exhibiting good natural dentitions. These values were compared to those of skull samples with complete natural dentitions. The results of this investigation suggested that there was a strong positive relationship between the angle of guidance formed by the palatal surfaces of the maxillary incisors and the angle of the articular eminence in subjects demonstrating good natural dentitions. The anterior guidance was approximately 5° steeper at the incisors as measured from the occlusal plane. This relationship is in agreement with recommended occlusal schemes for prosthetic dentistry[56-58]. An interesting finding in this study was that the condylar disclusive angle as measured with a Denar® pantograph was consistently larger than the angle of the articular eminence. This would suggest that the condyle does not exactly follow the slope of the articular eminence as suggested by Corbett[44].

Mongini[63] studied mandibular movements in a sample of subjects experiencing symptomatic Temporomandibular Dysfunction. Lateral polytomography and pantographic tracings were utilised in this study. Subjects who demonstrated a flattened condyle and flattened articular eminence on radiographic examination produced straight tracings while those with rounded condyles and convex articular eminences produced more curved pantographic tracings. This study again demonstrated the correlation between the TMJ morphology and the observed pathway of the mandibular condyle during mandibular movements.

3.5 Need for condylar guidance settings in prosthodontics

When attempting to undertake an extensive dental reconstruction using either fixed or removable prostheses or a combination of both it is advisable to use an appropriately adjusted articulator. The Glossary of Prosthodontic Terms[64] describes an articulator as:

> "A mechanical instrument that represents the temporomandibular joints and jaws, to which maxillary and mandibular casts may be attached to simulate some or all mandibular movements".

Articulators may be classified into 4 groups as described by Celenza[2] who makes recommendations for their selection and usage.

Classification	Recommended Use
Class I: Simple holding instruments capable of accepting a single static registration.	Particularly suited for centric occlusion restorations. Good crown and bridge or operative instruments
Class II: Instruments that permit horizontal as well as vertical motion. Not joint related.	Useful for the mounted position only. Eccentric movements offer no advantage.
Class III: Instruments simulate condylar pathways using averages/mechanical equivalents or both	Allow for joint orientation of casts. Complete dentures and teaching purposes.
Class IV: Instruments that will accept 3 dimensional dynamic registrations.	Allow for joint orientation of casts. Complete reconstructions and as teaching aids for advanced occlusal studies

Table 3-2 Classification of articulators after Celenza[54]

Using an articulator the clinician or technician can attempt to replicate the static and dynamic relationships of the dental arches. If any attempt is made to reproduce mandibular movement the posterior determinants should be recorded in the patient and reproduced in the articulator[1]. Most current articulators have either an adjustable condylar guide mechanism or condylar inserts which offer the possibility of more closely replicating the mandibular movements which were recorded clinically. Average condylar guide settings are included in most articulator systems and in many instances these are satisfactory. These values are arrived at from experimental data and population averages.[65-67]

The need for accurately placed anatomic restorations is discussed by Hobo et al.[1]:

> "The occlusal morphology of any restoration for the mouth must accommodate the free passage of the opposing teeth without interfering with the movement of the mandible".

This requirement in both the natural and restored dentition has been observed by others [51, 55, 68] and it is understood that articulators which can replicate mandibular movements are essential in order to produce restorations that will achieve harmonious function.

Four types of interference can be introduced as a result of inappropriate occlusal morphology. Centric interferences, which have been associated with parafunctional activity[69], working interferences (occurring between the palatal cusp of a maxillary posterior teeth and the lingual cusp of a mandibular posterior tooth during working side mandibular movement), protrusive interferences and non-working interferences which have historically been considered as destructive in nature.[70-73] Non-working side interferences were considered detrimental as they could cause potentially damaging fulcrum points about which the TMJs could be strained. While much modern evidence would suggest that this may not be the case it may be prudent to minimise the occurrence of interferences during prosthetic treatment in order to protect ceramic surfaces from potentially damaging shear forces and to minimise off-axis loading of implant restorations.

When placing multiple restorations or fixed partial dentures (FPDs) consideration should be given to the choice of instrumentation being employed. Interferences may be caused for a number of reasons when using an articulator, a mechanical equivalent, to simulate mandibular movement. Geometric factors such as condylar inclination setting, anteroposterior positioning of the casts, radius of opening of the articulator, intercondylar distance, the presence of Immediate Side Shift and the use of an arbitrary hinge axis may all contribute to errors being built into the prosthetic replacements. Hobo[1] introduces the idea of positive and negative errors.

In considering the effects of condylar inclination on the occlusal morphology of prosthetic teeth two situations must be considered.

1) When the condylar inclination of the articulator is steeper than that which occurs in the patient: posterior restorations made on such an articulator will have steeper cusps than can be accommodated for by the patient. When such restorations are placed positive errors are introduced. Interferences will occur in protrusive and lateral movements and occlusal adjustments are required as these are thought to be potentially damaging.

2) When the condylar inclination in the articulator is shallower than that which occurs in the patient: In this situation flatter cusps with shallower cuspal inclines and limited occlusal morphology will result. This leads to a negative error which provides greater clearance than is required at the expense of cusp morphology.

Guichet[74] advocated the controlled use of overcompensation to ensure a negative error when providing extensive prosthodontic treatment. This should not however lead to the provision of posterior restorations with a flat occlusal form. The need for well defined cuspal morphology in the prosthetic replacement of missing or damaged teeth is required to produce efficient, stable and aesthetically pleasing restorations and to ensure clinical longevity.[59, 75]

The condylar inclination not only affects protrusive and opening movements but also has an effect on lateral excursions as the non-working side condyle traverses downwards, forwards and medially across its fossa. The degree of immediate and progressive mandibular lateral translation (Immediate and progressive side shift) is also influential in the development of interferences. Wachtel and Curtis [76, 77] examined the effect of immediate mandibular lateral translation on the development of interferences at the level of the first molar. In the presence of <0.75mm immediate mandibular lateral translation the effects on the semi-adjustable articulator were negligible. When the immediate mandibular lateral translation was increased to 2mm considerable interferences occurred. This however could be adequately compensated for by appropriately adjusting the immediate mandibular lateral translation settings on the articulator (Immediate Side Shift settings).

When attempting to reproduce protrusive or lateral mandibular movement in a semi-adjustable or a fully adjustable articulator this occurs with guidance from the tooth contacts and the condylar guide mechanism. Posselt has clearly demonstrated the envelope of mandibular movement[78] which describes the border movements of the mandible.

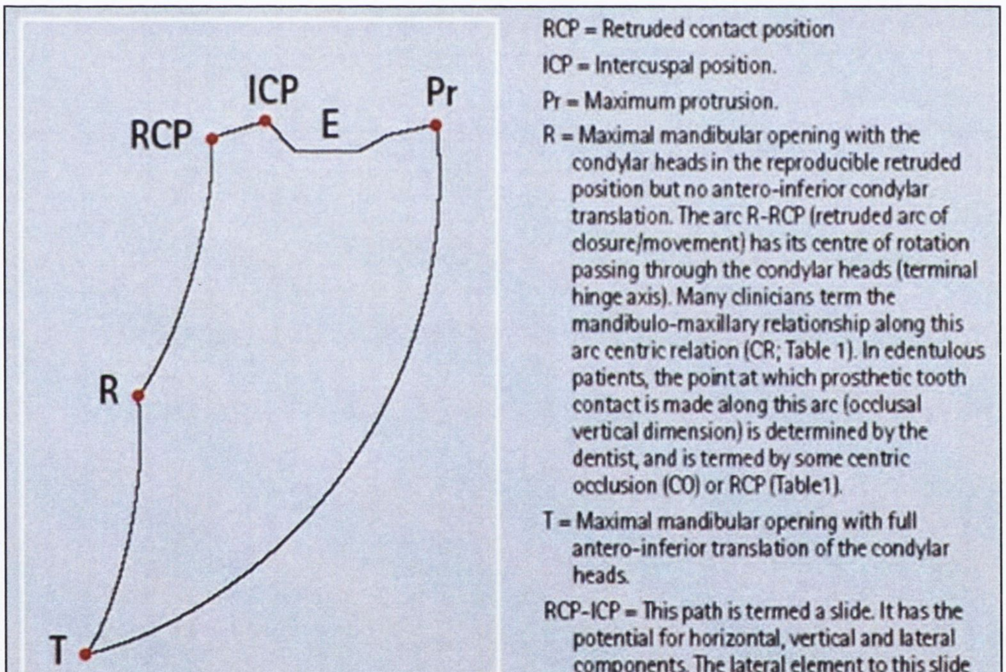


Figure 3-6 Posselt's envelope of movement in the sagittal plane.[79]

During functional movements of the mandible the pathway taken by a particular point lies within this envelope of movement.

Through the work of Gibbs and Lundeen using the Replicator system[80] much insight has been given to the intricacies of functional and parafunctional mandibular movement. While it is accepted that the articulator can faithfully reproduce border movements the same cannot be said for the habitual functional movements of the mandible. Nevertheless the need for accurately reproducing the border movements on the articulator becomes apparent when functional movements are more carefully scrutinised. In observing chewing patterns it has been demonstrated that on nearing final closure most chewing paths coincide with the working side border paths.[81] From experimental data it has been shown that upon final closing the gliding tooth contacts which occur on the working side guide the mandible into its position of maximum intercuspation. Therefore it becomes apparent that the use of lateral border registrations used in restorative dentistry is appropriate to functional chewing movements. Furthermore interferences which may occur during function may have the potential for causing damage and the occlusal form should coincide with the direction of mandibular movement during final closure.

Functional contact of the teeth consists of the fleeting contact which occurs during mastication and that which occurs during swallowing. The pattern during swallowing is believed to be similar to that which occurs during mastication with a sliding contact area in deglutition.[82]

The role of posterior or condylar guidance in determining mandibular movement should not be over-emphasised. The followers of Gnathology believe that the condylar guidance which occurs in the TMJ is immutable and should thus be recorded to ensure harmonious function of the masticatory system. As has been demonstrated the anterior guidance should be steeper than the posterior or condylar guidance. The influence of the anterior guidance on the condylar guidance has been researched. Researchers have experimentally increased the anterior guidance in subjects and observed the effects of this upon the condylar registrations obtained.[83, 84] Results from such experimentation show a decrease in immediate and progressive mandibular lateral translation on the working side condyle with a steeper lateral anterior guidance. It appears that the non-working side condylar pathway is not affected by such changes and may be considered as playing an active role during lateral excursions.

To produce long lasting efficient and aesthetic restorations without the potential to damage themselves or the masticatory system some attempt should be made to set the posterior determinants of the articulator if extensive prosthodontic treatment is being undertaken. An appropriate condylar inclination and immediate +/or progressive mandibular lateral translation setting will facilitate the provision of anatomically correct restorations which will function without interference.

3.6 Methods of recording the posterior determinants of mandibular movement.

Celenza[2] suggests that the eccentric pathways of patients can be dynamically registered either graphically (through the use of pantographic tracings) or stereographically (using an engraving method), positionally registered (using protrusive or lateral checkbites) or adjusted entirely within the patient.

	Type of Record	Example
1. Protrusive/Laterotrusive records	Positional	Wax records
2. Needle point tracing	Stereographic	Coble Balancer
3. Pantographic Tracings	Pantographic	Denar Pantograph
4. Electronic Pantograph/ Axiograph	Pantographic	Denar Cadiax Compact
5. Quick Analyser Systems	Pantographic	Whip-Mix Quick set recorder

Table 3-3 Methods commonly used to set Articulators

The Glossary of Prosthodontic Terms[64] defines a pantographic tracing as:

> "a graphic record of mandibular movement usually recorded in the horizontal, sagittal and frontal planes as registered by styli on the recording tables of a pantograph or by means of electronic sensors."

There is no definition given for an axiograph or axiographic tracing.

The mechanical pantograph consists of maxillary and mandibular clutches which are attached to mandibular and maxillary bows. Tracing styli attached to the mandibular bow scribe patterns on adjacent flags which are rigidly fixed to the maxillary bow adjacent to the TMJs. Horizontal flags are attached to the mandibular bow anteriorly and maxillary styli scribe bilateral Gothic arch tracings upon these as in the Stuart Gnathograph[3].

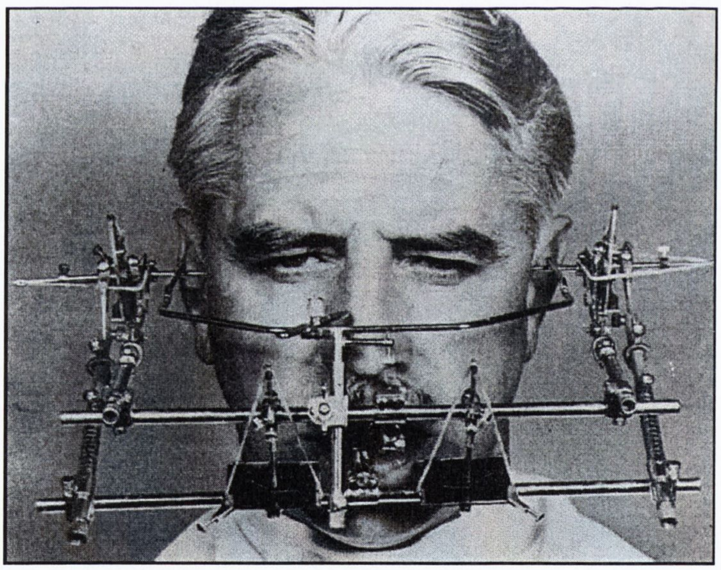


Figure 3-7 The Stuart Gnathograph[3].

The Denar design is somewhat different with all flags being attached to the maxillary bow. The tracings obtained are used to mechanically program a fully adjustable articulator.

The Denar® Pantronic, an electronic pantograph has replaced the mechanical pantograph. Recording flags are electronic and a computerised printout is obtained which can be used for programming the articulator. This design which has horizontal and vertical flags has been replaced by the Denar® Cadiax® Compact which has a vertical recording flag only. The stylus which lies perpendicular to this is telescopic and has additional electronic sensors to record horizontal movement[85].

Quick analyser systems such as the Panadent® AP Axi-Path III Recorder use mandibular clutches to trace the pathway of the transverse horizontal axis during protrusion and thus obtain a condylar inclination value for setting the articulator[86].

3.6.1 Protrusive and laterotrusive positional records

Christensen[47] first suggested that a protrusive wax record could be used as a means to set the condylar inclination for an articulator. Posselt and Franzen[87] made an attempt to evaluate the degree of error introduced when using a protrusive wax record. Using a semi-adjustable articulator and multiple protrusive wax records they reported a standard deviation ranging from 2.5° to 4.3° in condylar inclination settings. Many materials have been suggested for use in making a positional interocclusal record. Gross et al.[88] attempted to determine if there were significant differences between materials used for this purpose. Base plate wax, Copper wax and self curing acrylic resin were used to record the positional records (protrusion and laterotrusion). The records demonstrated great variability in condylar guide setting measurements when introduced to three semi adjustable articulators, Denar Mark II, Whip-Mix and Hanau 158. No material was demonstrated to be superior; however, lateral interocclusal records demonstrated higher reproducibility compared with protrusive interocclusal records. The articulators used also appeared to affect the condylar guide inclination settings obtained. The Denar Mark II gave the highest values while the Hanau 158 condylar inclination values were consistently lowest.

Mandibular facebows and simplified mandibular motion analysers have been used to measure the pathway followed by the mandibular condyle in protrusion. Ecker et al.[89] measured the accuracy of wax lateral interocclusal records with graphic measurements obtained using the Panadent Quick Analyser and the Whip-Mix Quick Set Recorder. Coprwax® lateral interocclusal records were shown to produce repeatedly wider ranges for articulator settings for both protrusive and Immediate Side Shift than those obtained with either of the quick analysers.

Another study[90] used a mandibular facebow (Condylator Services, Zurich, Switzerland) which produced a graphical representation of the condylar path during protrusion. One hundred and three subjects were examined. A tangent was drawn to the curved path and a protractor was used to determine the Sagittal Condylar Inclination. The average condylar inclination was found to be 32° for the left hand side and 31.5° for the right hand side relative to the occlusal plane. With this technique the within and between operator reproducibility was very high and it was considered as an accurate means of recording and reproducing the saggital condylar inclination. Lack of reproducibility has been considered a shortcoming for interocclusal positional records and the authors favoured this technique.

Further evidence to support the use of a pantographic method is offered by dos Santos [91]. This study examined 10 subjects free from signs and symptoms of any TMJ dysfunction. Wax protrusive records were obtained with 6mm of lower incisor protrusion. Casts were mounted in a Hanau articulator and the condylar inclination settings adjusted and recorded. Using a Whip-Mix Quick Set Recorder the same subjects were asked to move their mandible forwards and backwards. Tooth guidance was not made possible due to the position of a mandibular clutch overlying the mandibular teeth. Two or three measurements were made of each joint for each of the 10 subjects. The saggital condylar inclination value was obtained by drawing a tangent to the curve on the tracing and measuring this with a geometric protractor. Recordings made with the pantographic method produced greater saggital condylar inclination values (38.3°) than those obtained using wax interocclusal lateral records (29.8°). The standard deviations were also smaller (6.98°) with the pantographic method compared to the positional method (9.25°) suggesting that there is less variation when the Quick Set Recorder is used.

3.6.2 Stereographic tracings

Wise[92] describes a method of stereographically recording a patient's mandibular movement. Clutches are made for maxillary and mandibular arches and these are temporarily luted to the teeth. A cutting stud in one clutch makes cuts into the occlusal surface of the opposing clutch. The casts and clutches are then reassembled in the articulator and the movements made according to the pathways determined by the cut out areas. In such a manner the condylar processes can mould autopolymerising acrylic resin in the articular fossae and the articulator can then simulate the patient's movements.

3.6.3 Pantographic tracings

The mechanical pantograph has been considered the "Gold Standard" against which all other techniques for recording mandibular movement are judged. Winstanley[93] looked at the consistency of setting the articulator from a pantographic recording and observed that errors are not only introduced during the pantographic recording itself but also during the transfer to the articulator. The Immediate Side Shift varied up to 0.3mm, the progressive side shift could vary by up to 6° while the protrusive path varied by 2.5°. It has been claimed that the electronic pantograph can reduce this error as it provides absolute values to which the articulator is set.

Beard et al.[94] conducted a series of experiments on the Denar Pantronic, an electronic pantograph, with the intention of comparing it to the manual Denar pantograph. The mechanical and electronic pantographs were first tested *in-vitro* in their ability to reproduce known settings on an articulator. The electronic pantograph was more consistent in its ability to record and reproduce the articulator settings than its mechanical counterpart. It was observed that an inexperienced operator could achieve consistent readings through the use of the electronic pantograph and the potential error in transfer to the articulator was entirely eliminated. These researchers also assessed the performance of the Pantronic in an *in-vivo* setting. They concluded that the Pantronic performed as well and in some cases better than the mechanical Denar pantograph when the same operator made multiple records of one subject. Thirty subjects were then recorded by seven dentists using the Denar Pantronic electronic pantograph. Within each patients recording session the following was observed: The Immediate Side Shift values were within 0.3 mm for 97% of recordings, the Progressive side shift values were within 3° in 98.3% of recordings, the values of the protrusive path were within 3% in 98.3% of the recordings while the orbiting path was within 2° 91.7% of the time. From these observations it can be concluded that the use of an electronic pantograph is a highly accurate and reproducible method of recording mandibular movement.

Price and Bannerman[95] conducted a clinical experiment to evaluate the accuracy and reproducibility of articulator settings obtained from lateral interocclusal wax records and an electronic pantograph. The Denar Pantronic was tested in this experiment. Although only 2 subjects were used the number of repeated measurements was high. Ten sets of lateral interocclusal records were made for each subject and thirty pantographic recordings for both right and left sides were also made. The orbiting path articulator settings (Orb) were used as these measure the pathway of the non-working condyle which is also recorded in the lateral interocclusal record. While conceding that the pantographic method was more time consuming it was considered to be both more accurate and more reproducible than the lateral interocclusal method. The range of values obtained at different times demonstrated much greater variance with the lateral interocclusal record technique. Ninety five percent of the Orb settings were within 2.5° of the electronic pantograph mean while 95% of the interocclusal wax records were within 11.9-13.4° of the mean value. The 95% CI for progressive side shift settings were +/- 1.9° for the Pantronic and +/- 10.1° and +/-11.6° for the interocclusal wax records.

A recent study[96] was undertaken to compare the horizontal condylar inclination obtained using the Jaw Movement Analyzer (JMA: Zebris Medical GmbH, Max-Eyth-Weg 42, 88316, Isny im Allgäu, Germany) electronic recording system and a protrusive wax record for setting articulators. Twenty three subjects participated and wax records at 5mm protrusion were made for each. The kinematic hinge axis was then located and the horizontal condylar inclination again recorded at 5 mm protrusion using the JMA. The horizontal condylar inclination values from the protrusive records were measured using mounted casts on a SAM II and a Reference SL articulator. Agreement of the horizontal condylar inclination values as determined by the positional wax records was good between both articulators. The horizontal condylar inclination (HCI) value from the JMA was significantly higher compared to values obtained with wax records. The JMA was considered by the authors to be both valid and reliable. They concluded that due to the large variance observed when interocclusal records are used the use of a pantograph for the setting of an articulator should be considered.

Pelletier and Campbell[97] in an *in-vitro* study attempted to evaluate which methods most accurately recorded the Immediate

Side Shift and the protrusive condylar inclination. The most accurate protrusive condylar inclination values were obtained using an electronic pantograph (the Denar Pantronic), followed by the mechanical pantograph (Denar Pantograph) and the simplified mandibular motion analysers (The Denar and Whip-Mix). Comparing methods of recording the Immediate Side Shift the following hierarchy were established, the electronic pantograph, polyether interocclusal records, mechanical pantograph and Simplified mandibular motion analyser (Panadent), simplified mandibular motion analyser (Denar and Whip-Mix) and Zinc Oxide interocclusal records.

From the available evidence it can be concluded that pantographic methods, in particular electronic pantographs are well suited to obtain clinical data from mandibular movement and reproduce this in the articulator. When compared with values obtained using positional records the pantographic methods repeatedly produce higher values for saggital condylar inclination. These values and those for immediate and progressive side shift also demonstrate less variance and greater reproducibility when recorded by pantographic means.

3.7 Accuracy of CADIAX® Compact mandibular movement recording device

The Denar Pantronic recording device was introduced in the early 1980s but has now been largely replaced by the Denar Cadiax® Compact (Cadiax®Compact, Whip Mix Europe GmbH, Raudestraße 2, D-44141 Dortmund Germany). This instrument is a recording and evaluation system used primarily for the setting of dental articulators and screening of TMJ function[85]. This electronic pantograph utilises an arbitrary Transverse Horizontal Axis point and uses the axis orbital reference plane. The Cadiax® compact measures protrusion, left and right mediotrusion, opening and closing movements and has a condyle position measurement function which can discriminate between multiple recordings of a reference position. The Cadiax® Compact is based upon a coordinate system (figure 3.8) lying in the centre of each condyle. Mathematical manipulation of the recorded data allows the selection of appropriate articulator settings for the chosen articulator which best simulates the patient's mandibular movement. The system records mandibular movement for 5 seconds and calculates condylar settings over 3 condylotrack distances. This instrument is reported to calculate articular settings over 3mm, 5mm and 10mm of condylar translation. These settings are arrived at not from coordinate data at these specific distances but rather from information gathered over the entire movement from the origin to the recording distance. The Cadiax® Compact records translatory movement of the mandibular condyle which can then be used to individually programme the articulator.

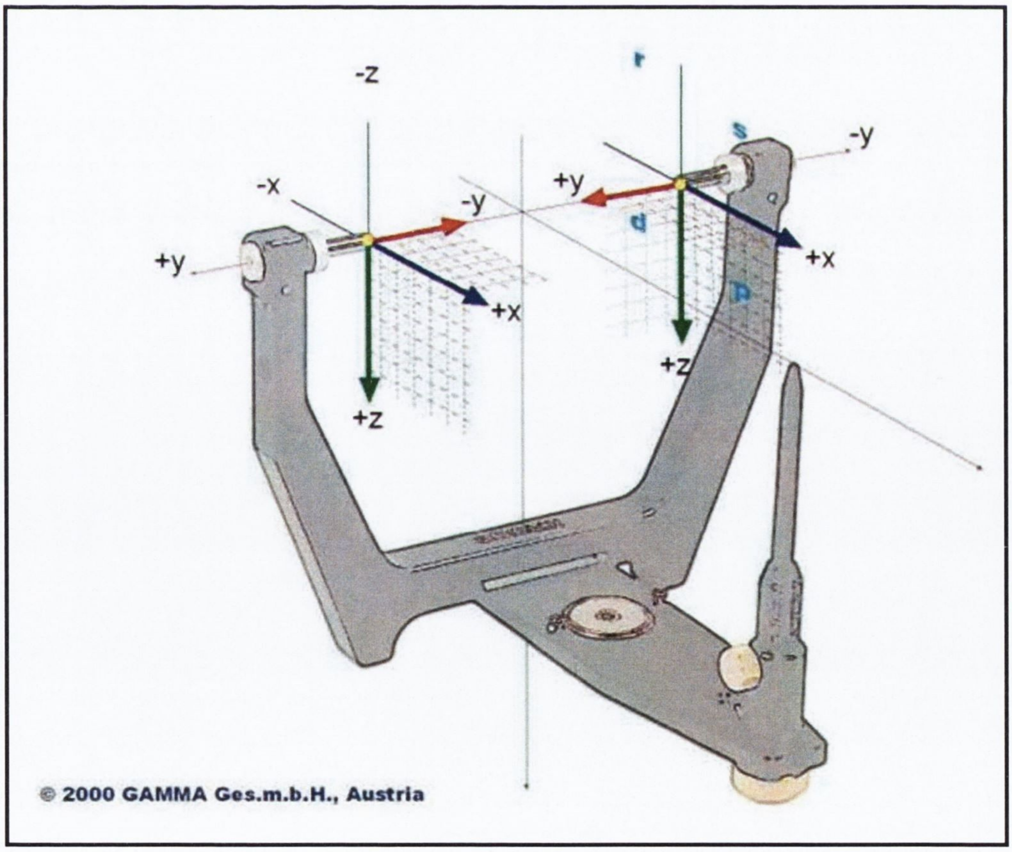


Figure 3-8 Compact Coordinate system. Picture courtesy of Ing. Christian Slaviceck.

In an attempt to measure the accuracy of the Cadiax® Compact Celar[98] conducted an *in-vitro* study. The Horizontal Condylar Inclination (HCI) and the Bennett angle were measured. The instrumentation was mounted on an Artex® Reference SL articulator. The maxillary bow of the Cadiax® compact with recording flags was attached to the upper member of the articulator while the mandibular bow with telescopic stylii was attached to the lower member. Articulator settings for HCI of 20°, 40° and 60° were used. A 3D digitiser was used as a means of validating the condylar angulation relative to the Cadiax® recording plate. Similarly a range of Bennett angle settings were applied to the articulator. Twenty protrusive recordings were made for each articulator setting. The Cadiax® Compact measured the HCI and the Bennett angle with a maximum error of 3.2°. The majority of measurements obtained from the Cadiax® Compact were statistically significantly different from those set in the articulator. This should be taken in context, however, as the average maximum error was 1.2°.

Articulator HCI setting	Cadiax®Compact HCI at 3mm	Cadiax®Compact HCI at 5mm	Cadiax®Compact HCI at 10mm
19.35+/-0.23	20.5 +/-0.51	19.9+/-0.31	19+/-0
39.43+/-0.14	39.25+/-0.85	39.1+/-0.79	38.5+/-0.51
59.62+/-0.33	58.3+/-0.92	58.9+/-0.72	58.8+/-0.41

Table 3-4 Cadiax® Compact measurements as recorded on Artex® Reference SL articulator.[98]

From the above table it can be seen that the Cadiax® Compact appears to faithfully reproduce the condylar inclination for protrusive movements. A similar finding was observed for lateral movements and the Bennett angle. The amount of error observed (mean 1.2°, maximum 3.2°) would be judged to be clinically acceptable.[98] The consistency standard set by Beard et al.[94] suggested that acceptable tolerances be in the region of 3° for progressive side shift and protrusive paths and 2° for the orbiting path.

A similar study was undertaken by Chang and colleagues[99] who attempted to test the reliability/validity of the Cadiax® Compact system in calculating the condylar settings for 5 different articulators.

Articulator	Model	Manufacturer
Denar	D5A	Waterpik Technologies, Ft Collins, Colo
Denar	Mark II	Waterpik Technologies
Whip Mix	8500	Whip Mix Corp, Louisville, Ky
Hanau	Modular	Waterpik Technologies
Panadent	PCH	Panadent Corp, Grand Terrace, Calif

Table 3-5 Articulators tested[99]

Specifically the authors wished to examine the reliability/validity at the 3mm, 5mm and 10mm condylotrack distances and determine which articulator produced the most valid readings. With the styli aligned to the Transverse Horizontal Axis of the articulator one operator executed all movements for each articulator. Thirty trials were made for each condylar determinant set to a fixed articulator value. Depending on the articulator being tested the following were recorded: horizontal condylar inclination (HCI), immediate mandibular lateral translation (IMLT), progressive mandibular lateral translation (PMLT), top wall and rear wall.

The reliability readings for HCI, IMLT and PMLT were more consistent at the 10mm condylotrack distance than at the 5mm, which was superior to the 3mm measurements. At the 10mm condylotrack distance the reliability for the HCI was demonstrated by the standard deviation (0.39°-0.64°), IMLT (SD 0.0183°-0.233°) and PMLT (SD 0.18°-0.97°). There were no significant differences between the articulators in this study. The smallest deviations from predetermined values occurred with Denar Mark II for HCI, Panadent PCH for IMLT and Denar Mark II for PMLT. The authors concluded that within the limitations of the study the Cadiax® Compact was confirmed to be both valid and reliable.

While *in-vitro* studies have proven the reproducibility of the Cadiax® Compact system its *in-vivo* performance had not been assessed until 2003. Petrie et al.[100] used the Pantographic Reproducibility Index to compare records of mandibular movement recorded by the Denar mechanical pantograph and the Cadiax® Compact computerised axiograph. The PRI gives a quantitative assessment of all 6 tracings obtained with a pantograph and gives a cumulative score on a scale of 0-144. Scores of 0-15 show high reproducibility and are observed in patients with normal healthy masticatory systems without signs or symptoms of TMD.[94] In the Petrie et al.[100] investigation 10 subjects had pantographic tracings made by both methods and both techniques were subsequently repeated after a 2-4 week period. For the mechanical pantograph PRI scores were calculated with and without the anterior tables of the pantograph. This was done as the Cadiax® Compact does not have anterior tables. From the recordings obtained only the mechanical pantograph with anterior tables demonstrated consistency across the two measurement intervals. When the PRI was calculated for the mechanical pantograph without the anterior tables this consistency level decreased considerably. The PRI scores for the initial and follow up computer axiograph recordings proved inconsistent. The consistency of the initial PRI scores comparing the mechanical pantograph and the computerised axiograph was very poor and similarly the consistency of the second PRI scores was low. This group concluded that the Cadiax® Compact demonstrated a lack of consistency over time. They also noted that the Centric Relation position could not be reproduced and/or recorded consistently using the Cadiax® Compact however this was not the case with the Denar Pantograph.

Another group lead by Bernhardt[101] conducted a series of clinical tests on the Cadiax® Compact system to evaluate whether there are clinically significant differences between the measurements obtained using a kinematically or an arbitrarily located Transverse Horizontal Axis (THA). Thirty volunteers without signs or symptoms of TMD were examined. Each had 2 recordings of mandibular movement registered with the Cadiax® Compact. The first recording utilised a non-adjustable mandibular bow and an arbitrary hinge axis. An adjustable mandibular bow and a kinematically located hinge axis were used for the second reading. A subset of 10 subjects had their mandibular movements recorded twice more on separate days using the Gamma Cadiax axiographic system. This was used to determine the kinematic horizontal axis. The investigators compared:

I. The correlation between readings obtained using an arbitrary and kinematic hinge axis with the Cadiax® Compact
II. The correlation between tracings using both arbitrary and kinematic hinge axes with the Cadiax® Compact and tracings obtained using both arbitrary and kinematic hinge axes with the Gamma Cadiax instrument.
III. Repeated recordings made with the Cadiax® Compact (using both arbitrary and kinematic hinge axes) were compared.

Interclass coefficients (ICC) were used to compare the angular values. The ICCs were classified as; <0.4=Poor reliability, 0.4-0.75= Fair to good reliability, and >0.75=Excellent reliability. The results of Bernhardt's[101] experimentation were as follows;

- Condylar inclination values determined kinematically and arbitrarily using the Cadiax® Compact demonstrated excellent reliability (ICC >0.8 with a SD of < 5°).

- Repeated measurements for the sagittal condylar angulation using an arbitrary and kinematic hinge axis with the Gamma Cadiax and the Cadiax® Compact demonstrated excellent reliability. (SD approximately 5°).
- Comparing repeated values of sagittal condylar angulation with both arbitrary and kinematic hinge axes using the Cadiax® Compact resulted in an ICC of 0.65 for the kinematic technique and 0.71 for the arbitrary. These values represent the higher end of the fair to good reliability spectrum. (SD approximately 7°).
- Repetition of tracings using the kinematic THA location using the Gamma Cadiax instrument demonstrated excellent reliability for sagittal condylar angulation with an ICC of 0.95 and a SD <3°
- Comparison of the transverse condylar inclination measured with the Cadiax® Compact using both the arbitrary and kinematic axes resulted in excellent reproducibility. The ICC was >0.8 and the SD approximately 3°.

These results taken together would indicate that an electronically calculated THA point from a kinematically determined THA appears to be the most precise method. Nevertheless, an acceptable level of reproducibility could be achieved through the use of the Cadiax® Compact system and an arbitrary hinge axis.

The accuracy of a predetermined THA and that of a kinematically located one was also investigated by Nagy et al.[102]. Numerous studies, most notably that of Schallhorn[103] have demonstrated the relationship between an arbitrary and kinematically located THA. This experiment[102] attempted to correlate the predetermined axis point on a mechanical SAM Axiograph III with that of a kinematically determined one located by means of a PC Axiotron ultrasonic axiograph. The results were favourable suggesting that the difference between arbitrary and kinematically located Axis points for the 80 samples measured was 1.1 +/- 0.63

mm. 96.2% were within 2 mm and 67.5% were within 1 mm. This is considered to be well within the clinical norm for estimated location of the transverse horizontal axis. Weinberg[104] stated that a maximum error of 5 mm at the transverse horizontal axis would create an error of 0.2 mm at the second molar in an anteroposterior direction.

3.8 Research on mandibular movement related to skeletal pattern/malocclusion.

Numerous authors, using various different techniques, have attempted to assess the possible correlation between the various skeletal patterns/orthodontic malocclusion classifications and mandibular movement [19-24].

Zimmer conducted the most thorough assessment of this problem to date[19]. Fifty seven non-orthodontically treated Caucasian patients who had no or minimal signs/symptoms of TMD were divided into three groups according to Angle's Classification. The groups consisted of 18 Class I subjects, 20 Class II subjects and 19 Class III subjects. All participants' maximum opening, maximum protrusion and maximum lateral movements were measured using a calliper. The same mandibular movements were then repeated and recorded with an electronic axiograph (SAS-Systems, Munich) following kinematic location of the THA. Multiple recordings were made for each participant.

Zimmer[19] observed that the Class II subjects were able to protrude and move their mandibles further laterally significantly more than the Class III group. Class II patients demonstrated greater protrusion than the Class I group. From the axiographic tracings the Class I and Class II patients were observed to exhibit significantly longer, steeper and more curved tracings than their Class III counterparts. When the initial inclination of the protrusive curves was measured the median values were 61° for the Class II group, 58° for the Class I group and 47° for the Class

III group. The differences observed were statistically significant between the Class I and the Class III groups, and between the Class II and the Class III groups. The difference between the Class I and the Class II groups was not statistically significant. Class I and Class II patients demonstrated more curved axiographic tracings while those of the Class III group were almost straight.

The effect of the inclination of the occlusal plane on mandibular movement has also been investigated. Ogawa[20] observed the masticatory movement in a group of 41 Japanese subjects with particular reference to the occlusal plane inclination. All subjects were adults with healthy TMJs and an Angle's Class I molar relationship. The inclination of the occlusal plane was recorded with reference to Camper's plane. A 3 dimensional mandibular movement analysing system designed by the authors was used. It consisted of maxillary and mandibular clutches to which light emitting diodes were attached. Two cameras including position sensitive detectors were used to record the movement of the mandible during mastication. In the analysis the incisal closing angle in the sagittal plane was examined as was the amount of balancing side condylar translation. The occlusal plane and the masticatory closing path of the mandible demonstrated a linear correlation at 5mm of separation. When the occlusal plane inclined in an anterior direction the incisor point closed in a posterior direction and vice versa. The authors demonstrated that the mandibular closing path maintained a consistent perpendicular relationship to the occlusal plane until the point of tooth contact. The balancing condylar translation was correlated with the occlusal plane inclination at 5mm from MIP. The timing of the balancing side condylar translation was seen to correlate to the inclination of the occlusal plane and this was effective in maintaining the perpendicular relationship between the masticatory closing path and the occlusal plane.

Patients demonstrating Class II division 2 malocclusions have come in for particular attention with respect to their mandibular movement. Stamm[21] examined the mandibular movements of a group of 23 Caucasian adults demonstrating a Class II division 2 incisor relationship. These subjects had no history of orthodontic treatment and no signs or symptoms of TMD. Their axiographic tracings were compared to those of an age and sex matched Class I control group. The Cadiax® Compact electronic axiograph system was used to record condylar movements. In protrusion the Class II division 2 patients demonstrated a significantly higher condylar path inclination when compared with the Class I group, the Class II division 2 being on average 7° steeper. The Class II division 2 patients demonstrated a wider range of motion than the control group with normal occlusion.

Anders[22] also conducted an axiographic examination of mandibular movement in a population with Class II division 2 incisor relationship. In this study 28 untreated Class II division 2 adolescents were compared with a control group with Class I occlusions. Three dimensional tracings of mandibular movement were obtained axiographically via a String Condylocomp LR3® electronic axiograph. This system utilises optoelectric data transmission and therefore there is no frictional impedence to the movements of the mandible. Mandibular movements were made with the teeth out of occlusion. Those patients with a Class II division 2 incisor relationship demonstrated greater maximum protrusion than the control group. This 0.9mm difference was considered to be statistically significant. The test group also demonstrated a greater condylar movement in a vertical direction during maximum opening than the control group. This difference while reaching statistical significance probably is of little clinical relevance. The condylar path inclination was higher for the class II division 2 group. The articular eminence inclination appeared to be steeper axiographically in the Class II division 2 group. This difference amounted to 4.5° in protrusion, 6° in opening and 4.3°

for mediotrusion. Overall the Class II division 2 patients had a greater capacity for mandibular movement especially in protrusion and a steeper condylar path inclination.

Another orthodontic malocclusion to receive specific attention is the Anterior Open Bite (AOB). This situation arises when the mandibular incisors have a negative vertical overlap relationship in relation to the maxillary incisor teeth. Ari-Demirkaya et al.[23] attempted to assess the relationship between AOB malocclusions and mandibular movement. Ninety dental students participated in this study and were separated into 3 groups, normal overbite (2-4 mm), deep overbite (>4 mm) and open bite (<0 mm). A SAM mandibular positioning indicator and a manual SAM axiograph were used to collect data (SAM Präzisionstechnik GmbH, Fussbergstraße 1, D-82131 Gauting bei München, Germany). Axiographic tracings were made of both sides for opening-closing and also for protrusion-retrusion. The SAM MPI instrument was used to determine the extent of CR: CO slides. The percentage of patients with vertical CR: CO slides >1mm was significantly greater in the negative vertical overlap group (50%) than in the increased vertical overlap (33%) or control (17%) groups. No difference in anteroposterior slides was observed between the groups. A transverse slide greater than 1mm was observed more frequently in the deep bite groups (33%) than the open bite or control groups (both 13%).

Axiographs were observed for:

I. The angle formed between a tangent drawn from the initial curve of the condylar path to the reference line
II. The length of the projection of the condylar path onto the reference line.

There were no correlations between the steepness of the condylar path and the degree of AOB. A weak correlation was observed between the length of the condylar path (in opening and protrusion) and overbite. The findings of this study would suggest that open bite cases are associated with larger CR: CO slides and have decrease protrusive paths compared to those with a normal or increased overbite.

Koak et al[24] also conducted a study in relation to the mandibular movement of AOB patients. Two types of instrumentation were used for recording mandibular movement. A sample of AOB patients (n=15) and a control group (n=28) were subjected to analysis using an electronic pantograph, the Denar Pantronic. A Saphon Visi-Trainer Model 3 (Shizaista Co., Tokyo, Japan) was also used. This instrument utilises Light Emitting Diodes (LEDs) attached to the mandibular incisors and can produce border tracings similar to Posselt's Envelope[78] in 3 planes of space.

With regard to the Pantronic measurements there were no statistically significant differences between the Immediate Side Shift values for either group. A significant difference was observed between the lateral condylar guide angles, with the control group having a steeper inclination. Similarly a statistically significant difference was observed between the anterior guidance angles in protrusion. The control group had a protrusive angle of 37.14° +/-7.22° and 35.07° +/-7.07° for the right and left sides respectively. The equivalent readings for the AOB group were 30.73° +/-9.48° and 29.07°+/-9.45°. The Visi-Trainer was also capable of showing differences between the groups. The distance for CR:CO was 1.08mm in the control group and 0.26mm in the AOB group. The angle of protrusion when viewed sagittaly at the mandibular incisor point was 54.5° for the controls and 30.6° for those with an AOB. In the frontal plane the maximum opening was 40.04mm for control and 34.45 mm for those with an AOB. The angle of laterotrusion was 30.26° in controls and 22.98° in the AOB group.

Koak's[24] findings are suggestive of a flatter condylar inclination in Anterior Open Bite cases and the function of the TMJ appears to be restricted in these patients when compared with normal occlusal relationships.

3.9 Aims of the present study.

From the available literature it appears that there may be a relationship between a patient's mandibular condyle/articular fossa morphology and their skeletal pattern or facial morphology. As the condyle has been demonstrated to translate along a path which closely correlates to the articular eminence it may be assumed that the underlying osseous morphology influences resultant mandibular motion. The aim of the present study is to investigate the possible role of skeletal pattern on mandibular movement, as judged by profile photographs. An electronic pantograph will be used to obtain articulator settings from a group of patients demonstrating different skeletal patterns. These settings will be examined to determine to what extent, if any, the articulator settings vary among patients from the different orthodontic categories.

Specifically this study aims to:

I. Record the average measurements for Sagittal Condylar Inclination, immediate mandibular lateral translation (formerly Immediate Side Shift), and progressive mandibular lateral translation (formerly progressive side shift) in a sample population consisting of Class I, Class II and Class III subjects, as judged by profile photographs.
II. Investigate whether there are significant differences for the Sagittal Condylar Inclination, immediate mandibular lateral translation, and progressive mandibular lateral translation between these groups.

III. To make recommendations regarding "average values" for use in the prosthodontic management of these groups of patients.

The null hypothesis for this research project is that there is no difference in articulator settings between groups of patients demonstrating different skeletal patterns.

4. Materials and Methods

4.1 Protocol and Ethical Approval

A research protocol was drafted and presented in accordance with Dublin Dental School and Hospital (DDSH) DDentCh syllabus (Appendix 8.2.1). Ethical approval was sought and granted from both Trinity College Dublin Faculty of Health Sciences Research Ethics Committee and the Research Ethics Committee for the Adelaide & Meath Hospital, incorporating The National Children's Hospital (Appendix 8.2.2).

4.2 Recruitment of subjects

Subjects were recruited for the study from a population of undergraduate and postgraduate dental students at the DDSH, patients attending the postgraduate prosthodontic clinics at the DDSH and patients of the Health Services Executive (HSE) regional orthodontic units. The HSE regional orthodontic units used in the study were located at St. James Hospital, Dublin 8 and Ashtown Gate, Dublin 7.

A power analysis of the initial data was conducted in an attempt to estimate an appropriate sample size. In an attempt to increase the number of subjects the participants were selected in a non-randomised fashion.

Subjects from within the DDSH were first requested to participate by the principal investigator in person. Subjects from the HSE orthodontic clinics were contacted by telephone and requested to participate in the study. No incentives were offered to participate.

4.3 Inclusion and exclusion criteria

Subjects were included for examination if they were 18 years or older, with an adult dentition, had greater than 12 opposing posterior teeth and were deemed functionally normal using the DDSH functional assessment criteria. (Appendix 8.3).

Subjects were excluded from participating in the study if they demonstrated a limitation of opening, history of Temporomandibular Dysfunction, were undergoing active orthodontic treatment, had mobile or absent mandibular anterior teeth or symptomatic internal derangement of the TMJs. In the presence of TMJ clicking any participant with a history of symptomatic TMJ noise, locking or discomfort was excluded.

Inclusion Criteria	Exclusion Criteria
>18 years of age	Limitation of opening
Adult dentition	History of TMD
>12 opposing teeth	Active orthodontic treatment
Within the limits of the DDSH functional assessment criteria	Mobile or absent mandibular anterior teeth
	Internal derangement of TMJ

Table 4-1 Inclusion and exclusion criteria.

4.4 Information sheet and informed consent

Each participant who verbally agreed to participate was provided with an information sheet and an informed consent sheet as per TCD Faculty of Health Sciences Research ethics Committee guidelines. (Appendix 8.2.1). Participants were requested to read the information sheet and provide their written consent prior to entering the study. Contact details of the lead investigator and supervisor were provided should clarification be required. At the data recording visit the procedure was outlined and explained to each participant before recordings were made.

4.5 Data recording procedure

4.5.1 Profile photographs

Having consented to participate each subject was examined by the lead investigator. A profile photograph was obtained with the subject facing to the right with the Frankfort Plane horizontal and the teeth in the Maximum Intercuspation Position (MIP). Profile photographs were taken using a digital SLR camera (Canon 20D). Photographs were standardised at a focal length of 105mm, ISO speed 100, Aperture Value F14 and shutter speed 1/125s. Each subject was allocated a personal identification code and the photographs were stored on a personal computer (MESH Matrix Premium XLM, AMD Athlon™ 64). The chief investigator and the supervisor only had access to the profile photograph file which was password encrypted.

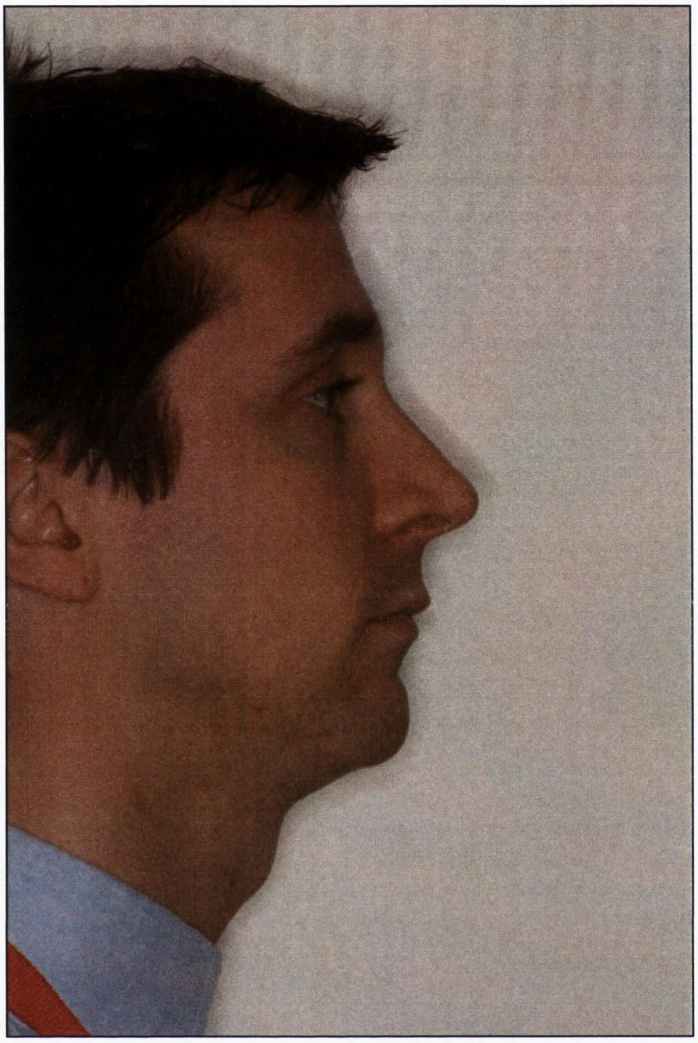


Figure 4-1 Subject profile photograph.

4.5.2 Clinical measurements

All participants were subjected to a brief clinical examination where a functional assessment as per the DDSH protocol was undertaken. A history of TMJ noise, locking or pain was recorded. Vertical overlap at the incisor teeth was measured with a steel ruler and recorded. Range of motion recordings were obtained for maximum passive opening and left and right lateral excursions. Any limitation of opening or deviation in line of movement was noted. Incisor relationships were recorded according to the British Standards Institute Classification system[31] (Appendix 8.6). Molar relationship was recorded for left and right sides according to the Angle's Classification System[29] (Appendix 8.7). In the case of missing first molars canines were substituted in this classification system. Each subject was classified according to underlying skeletal pattern as judged by the lead investigator at the time of examination. Where available copy radiographs were made from existing lateral cephalograms to assist in determining the underlying skeletal pattern.

Data was recorded on a clinical data recording sheet (Appendix 8.8) using the individual's personal identification code. Data sheets were stored in a locked container to which only the lead investigator and supervisor had access.

4.5.3 Rehearsing mandibular movements

Mandibular movements of interest were first rehearsed by the subject. An explanation and demonstration was given by the investigator as to the movements which were to be executed. Participants were seated upright in a dental chair with the Frankfort plane parallel to the floor. Participants were requested to relax their mandibular musculature and allow their teeth to approximate but not touch. Using this method the reference position was located from which all movements were to originate and terminate. Participants were asked to protrude maximally and return to the reference position in a smooth manner. Left and right lateral movements and maximal opening were rehearsed similarly. When the investigator was confident in the patient's ability to obtain the reference position and execute the mandibular movements the electronic recording procedure was undertaken.

4.5.4 Electronic recording of mandibular movements

A Cadiax®Compact electronic pantographic recording device was used to obtain digital recordings of each participant's mandibular movement. This recording device consisted of a mandibular clutch, a mandibular bow, a parallel facebow with retention straps, hinge axis locator pins, mini-computation unit with display, foot pedal, measuring flags and measuring styli.

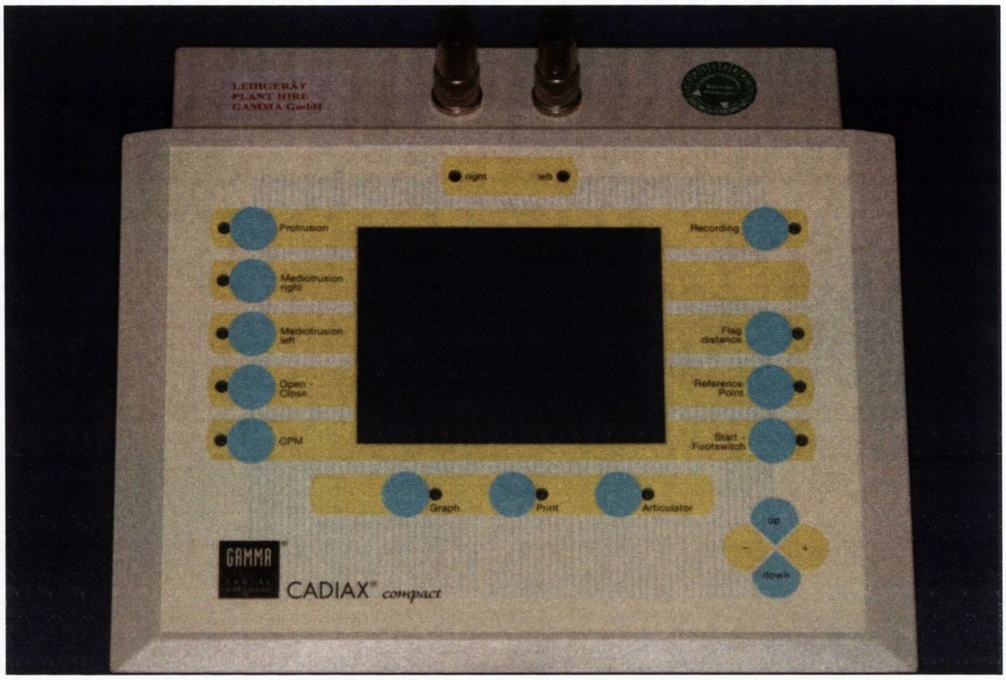


Figure 4-2 Cadiax® Compact Unit.

The computation unit was connected to a laptop personal computer and the recorded data was stored using the Gamma Dental Software® version3 package (Gamma medizinisch wissenschaftliche Fortbildungs Gesellschaft mbH, Josef-Brenner-Straβe 10-A-3400, Klosterneuburg, Austria.)

4.5.5 Procedure for recording mandibular movements

Silicone adhesive was applied to the mandibular clutch. The clutch was attached to the mandibular anterior teeth using Kerr Take1Bite™ PVS bite registration material (KerrHawe SA, Via Strecce 4, P.O. BOX 268 6934 Bioggio, Switzerland). A Kerr Extruder (KerrHawe SA, Via Strecce 4, P.O. BOX 268 6934 Bioggio, Switzerland) was used to mix the PVS material and apply it to the clutch.

Figure 4-3 Silicone adhesive, mandibular clutch and PVS occlusal registration material.

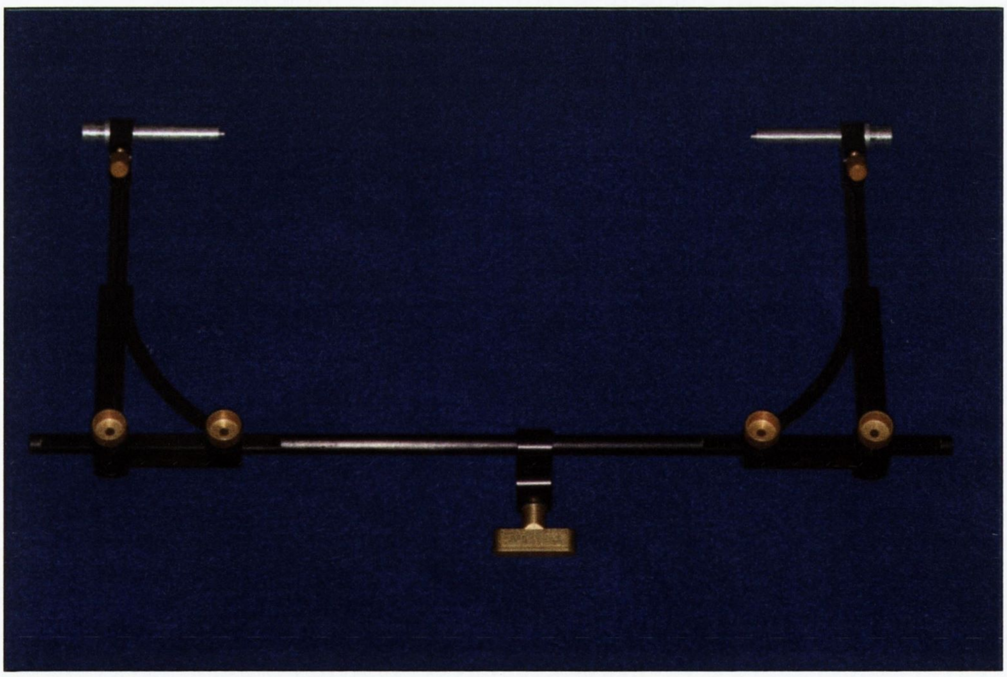


Figure 4-4 Mandibular bow with axis locator pins attached.

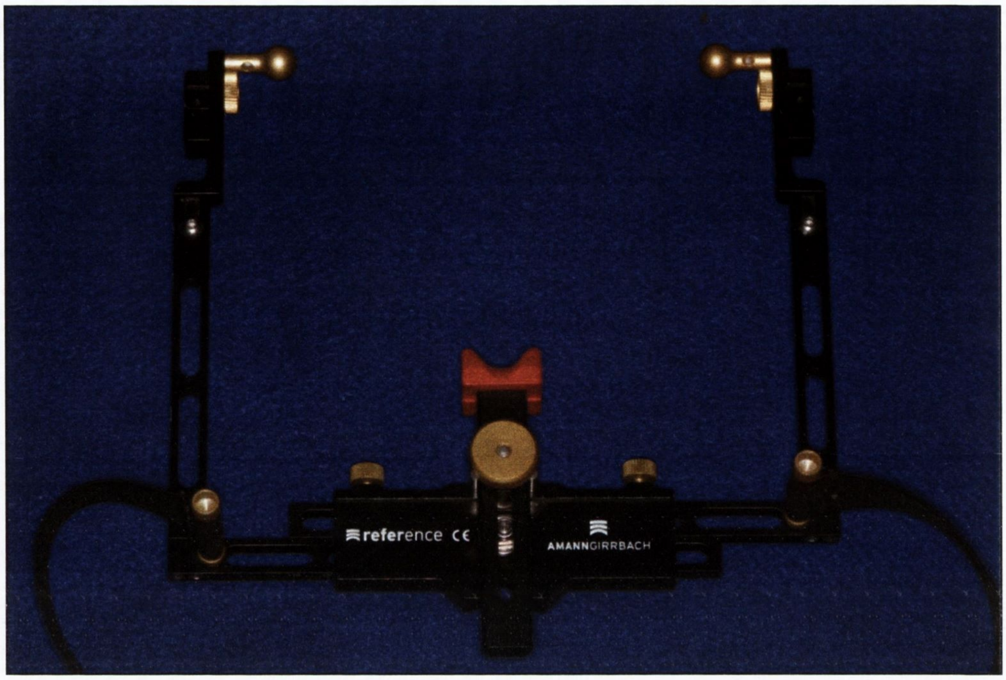


Figure 4-5 Maxillary facebow with retention straps.

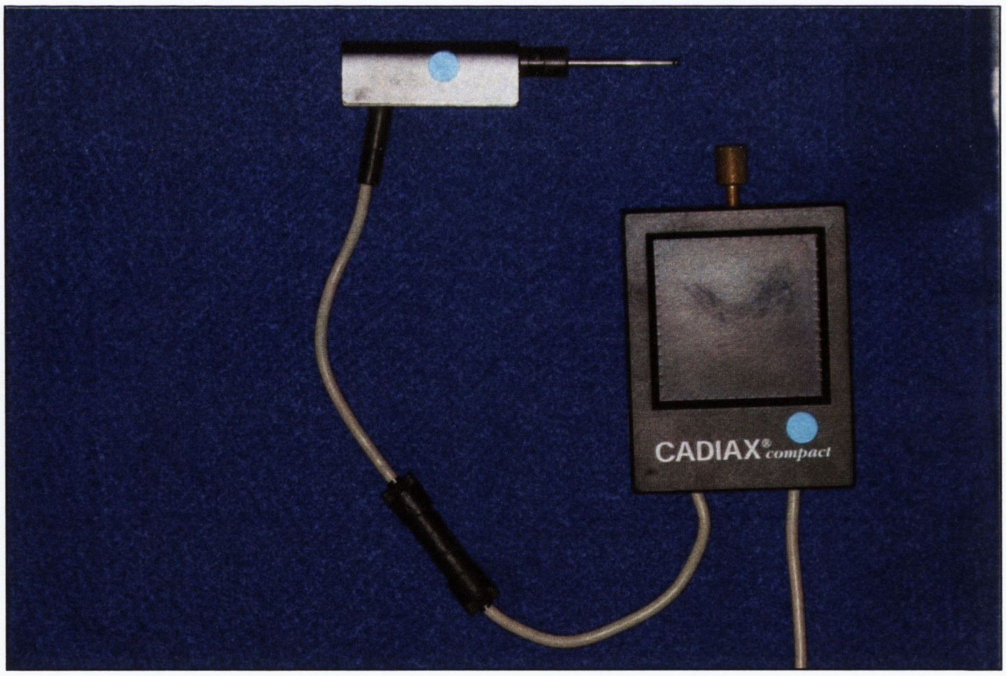


Figure 4-6 Electronic flag and stylus.

With the subject seated upright in the dental chair the parallel face- bow was attached to the maxillary arch. The anatomic facebow was placed with the ear pieces inserted into the eternal auditory meati with the assistance of the participant. The face-bow width was secured by tightening the clamping screws on the front crossbar. With the subject lightly holding the facebow frame the glabella support was positioned and tightened. The elastic straps were pulled tight and fastened above the occipital protuberance. The axis locator pins were attached to the mandibular bow and the bow was guided along the pin of the mandibular clutch. The participant was asked to place the mandible in the previously rehearsed reference position with the teeth close to the clutch but not occluding on it. The axis locator pins were inserted into the axis guide holes of the parallel facebow (maxillary arch). The subject assisted in maintaining the position of the guide pins in the guide holes until final assembly of the mandibular bow was completed. The crossbar of the mandibular bow was set tension-free and parallel to that of the anatomic facebow and the double tightening screws fastened. The electronic flags were next attached to the cranial face-bow behind the side arms of the mandibular writing bow. The electronic styli were then connected to the mandibular bow and secured by tightening the retaining screw. The flag cable was connected to the Cadiax®Compact and the indicator light shone green to verify contact within the system. The assembled pantographic instrumentation is illustrated below.

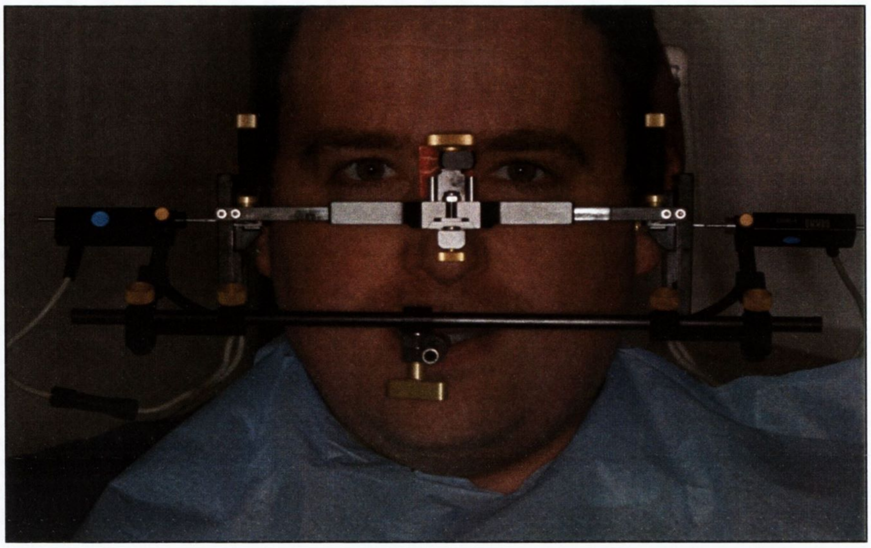


Figure 4-7 Cadiax® Compact assembled on a subject.

The first data recorded on the Cadiax®Compact was the Flag Distance. This was read from the millimetre scale on the crossbar of the cranial face-bow and inputted into the recording device. The reference position was recorded by asking the subject to place the mandible in the pre-rehearsed position with the mandibular musculature relaxed and the teeth just out of contact with the mandibular clutch. When this was observed to be stable the foot pedal was depressed and the position recorded.

The following mandibular movements were executed and recorded: protrusion, mediotrusion right, mediotrusion left and opening/closing. In an attempt to verify the reproducibility of the reference position its location was recorded three times after the mandibular movements were completed. The subject was asked to protrude and open/close and return to the original reference position.

For protrusive movements the subject was asked to maximally protrude the mandible and return it to the reference position. The operator demonstrated this and the subject then executed the movement. The foot pedal was depressed immediately prior to the subject protruding the mandible and a 5 second recording was obtained. In the case of an incomplete recording where the protrusion and retrusion to the reference position was not completed within the 5 second period a second recording was obtained.

The recording procedure was similar for mediotrusion right, mediotrusion left and opening/closing movements. In mediotrusion right the subject was asked to move the mandible as far as possible to the left hand side and then return it to the starting reference position. This was recorded for 5 seconds by depressing the foot switch prior to commencement of movement. In recording mediotrusion left the same procedure was followed but the subject was asked to move the mandible maximally to the right hand side and back to the reference position. Opening and closing was recorded with the subject maximally depressing the mandible and returning to the reference position.

Before any movements were recorded the position of the hinge axis relative to the recorded reference position was observed. If there was an obvious deviation (>0.7mm) the subject was asked to return the mandible to the reference position[105]. In cases where this did not improve the mandibular position a new reference position was recorded prior to any further mandibular movement recordings.

When a recording was incomplete or appeared to deviate from expected norms a second recording was obtained. The operator attempted to make a single complete recording of each mandibular movement for every subject. With the mandibular movement data obtained the CPM (Condylar Position Measurement) utility on the Cadiax®Compact was used to assess the degree of reproducibility of the reference position for each participant. This function records the positions of the X, Y and Z co-ordinates of the axes of rotation for a given condylar position. Subjects were asked to protrude and return the mandible to the reference position and open and close their mouth and return to the reference position.

Three recordings of the reference position were made and it was possible to observe the variation in the reference position within subjects in this manner.

When a satisfactory complete set of recordings had been obtained from the participant the recording flags and styli were removed. The mandibular bow was separated from the mandibular clutch and the anatomic facebow loosened and removed. Finally the clutch was carefully removed from the mandibular teeth.

4.5.6 Storage of recorded data

The Cadiax®Compact can only store one set of complete recordings. The unit was connected to a laptop personal computer throughout the experimental recording procedure. Using the Gamma Dental Software® version 3 package it was possible to store and analyse multiple recordings. Each subject's data was entered immediately after the recordings were obtained. A file was created under the participant's personal identification code and the recorded data stored electronically. Recorded data was duplicated in the event of data loss. Both sets of recorded data were stored in password protected files to which only the operator had access. When the data was transferred to the personal computer the memory of the Cadiax®Compact unit was cleared in preparation for the next recording.

4.6 Allocation of subjects into study groups

A PowerPoint (Microsoft® Office PowerPoint 2007) slide show was constructed in which the subjects' profile photographs appeared in a random order. Three senior staff from the orthodontic department and three senior staff from the restorative department of the DDSH were recruited for assessment of the subjects underlying skeletal pattern. A data recording sheet was provided (appendix) and scores for horizontal and vertical skeletal type were obtained. A correlation test was used to determine the agreement between the orthodontists and the restorative dentists in assessment of skeletal pattern. Subjects were allocated to groups according to their horizontal or vertical skeletal classification. Six study groups were examined;

- ***Sagittal I***, demonstrating a Class I sagittal skeletal pattern.
- ***Sagittal II***, demonstrating a Class II sagittal skeletal pattern.
- ***Sagittal III***, demonstrating a Class III sagittal skeletal pattern.
- ***Reduced Vertical,*** demonstrating a reduced vertical skeletal pattern when viewed sagittaly.
- ***Average Vertical,*** demonstrating an average vertical skeletal pattern when viewed sagittaly.
- ***Increased Vertical,*** demonstrating an increased vertical skeletal pattern when viewed sagittaly.

4.7 Statistical testing of study groups

Data obtained for each subject from the data recording sheets (clinical and skeletal assessment, appendix) was entered into an Excel spreadsheet (Microsoft® Office Excel 2007). The Gamma Dental Software® version3 package was used to obtain articulator values for each subject. Articulator settings for the Denar®Mark II were utilised for comparison between groups. This articulator can be adjusted for sagittal and transverse condylar guidance and Immediate Side Shift. Each subject's pantographic data was used to obtain their individual articulator settings. Statistical analysis was undertaken to determine the following:

I. Testing for normality of Data recorded.
II. Correlation between multiple readings for pilot group.
III. Correlation coefficient between the clinical assessors (orthodontists versus restorative dentists) to determine allocation of subjects according to horizontal and vertical skeletal pattern.

IV. Mean and standard deviation of Sagittal Condylar Inclination, transverse condylar inclination, ISS and CPM for the whole sample population.

V. Mean and standard deviation of Sagittal Condylar Inclination, transverse condylar inclination, ISS and CPM for the subjects who had previous orthodontic treatment.

VI. Mean and standard deviation of Sagittal Condylar Inclination, transverse condylar inclination, ISS and CPM for the subjects who had no previous orthodontic treatment.

VII. Mean and standard deviation for Sagittal Condylar Inclination for Class I subgroup.

VIII. Mean and standard deviation for Sagittal Condylar Inclination for Class II subgroup.

IX. Mean and standard deviation for Sagittal Condylar Inclination for Class III subgroup.

X. Mean and standard deviation for Sagittal Condylar Inclination for the reduced vertical subgroup.

XI. Mean and standard deviation for Sagittal Condylar Inclination for the average vertical subgroup.

XII. Mean and standard deviation for Sagittal Condylar Inclination for the increased vertical subgroup.

XIII. Mean and standard deviation for transverse condylar inclination for Class I subgroup.

XIV. Mean and standard deviation for transverse condylar inclination for Class II subgroup.

XV. Mean and standard deviation for transverse condylar inclination for Class III subgroup.

XVI. Mean and standard deviation for transverse condylar inclination for reduced vertical subgroup.

XVII. Mean and standard deviation for transverse condylar inclination for average vertical subgroup.

XVIII. Mean and standard deviation for transverse condylar inclination for increased vertical subgroup.

XIX. Mean and standard deviation for Immediate Side Shift for Class I subgroup.

XX. Mean and standard deviation for Immediate Side Shift for Class II subgroup.

XXI. Mean and standard deviation for Immediate Side Shift for Class III subgroup.

XXII. Mean and standard deviation for Immediate Side Shift for the reduced vertical subgroup.

XXIII. Mean and standard deviation for Immediate Side Shift for the normal vertical subgroup.

XXIV. Mean and standard deviation for Immediate Side Shift for the increased vertical subgroup.

XXV. Mean and standard deviation for reference position reproducibility for Class I Subgroup.

XXVI. Mean and standard deviation for reference position reproducibility for Class II Subgroup.

XXVII. Mean and standard deviation for reference position reproducibility for Class III Subgroup.

XXVIII. Mean and standard deviation for reference position reproducibility for reduced vertical Subgroup.

XXIX. Mean and standard deviation for reference position reproducibility for normal vertical Subgroup.

XXX. Mean and standard deviation for reference position reproducibility for increased vertical Subgroup.

R statistical software was used in order to facilitate statistical evaluation of the recorded data. This software can be downloaded from the internet free from http://ftp.heanet.ie/mirrors/cran.r-project.org/

Significance testing was undertaken to determine the effect of horizontal and vertical skeletal pattern on the Sagittal Condylar Inclination values using the Student's t-test.

An independent statistician was employed for the purposes of assessment of the research data.

5. Results

5.1 Allocation of participants into study groups.

A series of facial photographs of participants was arranged in a PowerPoint (Microsoft® Office PowerPoint 2007) slide show. Three orthodontists and three prosthodontists were asked to view these profile photographs and complete a data recording sheet (appendix 8.8). Each assessor provided a score for both sagittal (sagittal I, sagittal II or sagittal III) and vertical (reduced vertical, average vertical or increased vertical) skeletal pattern for each subject. This data was collected and entered into an Excel (Microsoft® Office Excel 2007) data sheet (appendix 8.9). In total six scores for sagittal and six scores for vertical classification were obtained for all subjects.

On the basis of these scores the subjects were then allocated into the various study groups. Each subject was assigned to both a sagittal and a vertical group. In cases of disagreement between the prosthodontists and the orthodontists the opinion of the orthodontists was given preference.

Table5.1 shows the distribution of subjects into their respective study groups.

	Number of Subjects		Number of Subjects
Sagittal I	16	**Reduced Vertical**	20
Sagittal II	42	**Average Vertical**	42
Sagittal III	15	**Increased Vertical**	11
Total	73	Total	73

Table 5-1 Allocation of subjects to study groups.

In addition to analysing subjects on the basis of their sagittal and vertical skeletal pattern subgroups were made to determine if a history of previous orthodontic treatment had an effect on the values observed. During clinical data recording subjects were questioned regarding prior orthodontic treatment.

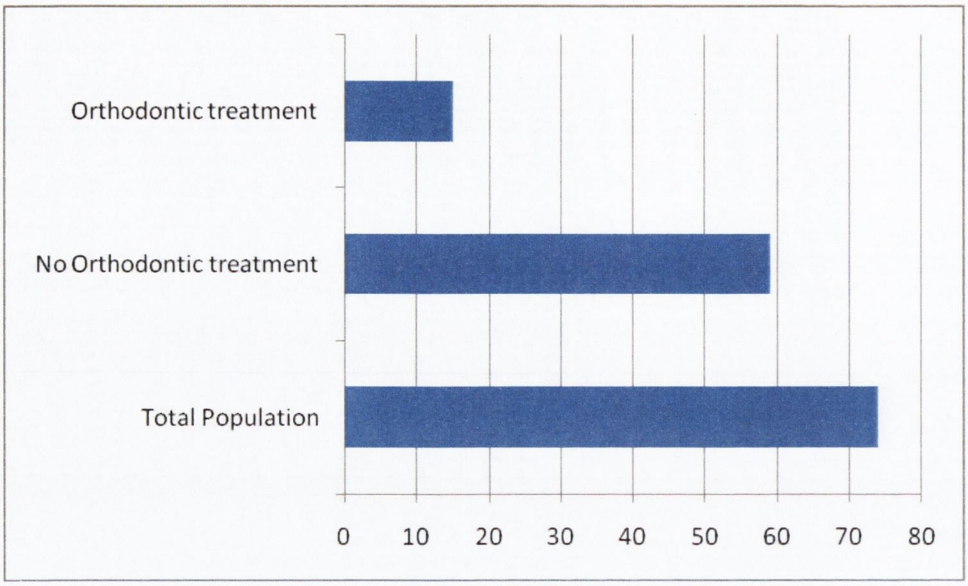


Figure 5-1 Distribution of subjects with positive history of orthodontic treatment.

5.2 Reproducibility of electronic pantograph.

In an attempt to evaluate errors in reproducibility in the present study a subset of patients were subjected to repeated measures. A sample of convenience was used and subjects from within the student population were asked to be subjected to repeated measures. Analysis of their articulator settings for multiple readings suggested that single values could be applied to the sample groups.

	Sagittal Inclination RHS	Sagittal Inclination LHS	Transverse Inclination RHS	Transverse Inclination LHS	Immediate Side Shift
Pilot # 1					
Reading A	39	37	5	6	0
Reading B	42	36	5	5	0
Reading C	42	36	5	5	0
Mean (SD)	41+/- 1.7	36.3+/-0.58	5+/-0	5.3+/-0.58	0+/-0
Pilot # 2					
Reading A	44	41	12	5	0
Reading B	44	46	9	5	0
Reading C	44	47	10	5	0
Mean (SD)	44+/-0	44.7+/-3.2	10.3+/-1.5	5+/-0	0+/-0
Pilot # 3					
Reading A	48	42	5	5	0
Reading B	49	44	5	5	0
Reading C	49	45	5	5	0
Mean (SD)	48.7+/-0.6	43.7+/-1.5	5+/-0	5+/-0	0+/-0

Table 5-2 Data from reproducibility pilot study.

The standard deviation of the multiple articulator recordings for these subjects was low. It was therefore considered appropriate to use a single complete recording of protrusion, mediotrusion left, and mediotrusion right and opening/closing for each participant. If the examiner considered a recording to be aberrant it was reproduced and then stored for analysis.

As a further means to assess patient's reproducibility the reference position from which all movements originated was recorded using the CPM function of the Cadiax® Compact.

5.3 Presentation of results.

Results from the articulator settings obtained from each population are presented below. Results have been calculated for the whole study population, and also for cohorts who had either previous orthodontic treatment or those who had no history of orthodontic treatment.

The following abbreviations have been used:

THG right	Transverse Horizontal Guidance on the left hand side.
THG Left	Sagittal Condylar Inclination on the right hand side.
SCI left	Sagittal Condylar Inclination on the right hand side.
ISS right	Immediate Side Shift on the right hand side.
ISS left	Immediate Side Shift on the left hand side.
Ortho	Subjects who had a history of orthodontic treatment.
No-ortho	Subjects who did not have a history of orthodontic treatment.
All	The entire study population.
s.d.	Standard deviation.

5.4 Scatter plots of data recorded.

The figures below describe the distribution of the data recorded for the measurements of Transverse Horizontal Guidance, Sagittal Condylar Inclination and Immediate Side Shift obtained from the study groups. Values are presented according to sagittal and horizontal skeletal pattern. Values obtained from both the right and left hand sides are grouped together.

Figure 5.2 demonstrates the distribution of the values obtained for the Sagittal Condylar Inclination and the Transverse Horizontal Guidance for all subjects evaluated in the study. On examination of the data recorded, the values for Sagittal Condylar Inclination were observed to be normally distributed. Those for the

Transverse Condylar Guidance were not normally distributed and demonstrated a clustering about the minimum, and to a lesser extent, the maximum values.

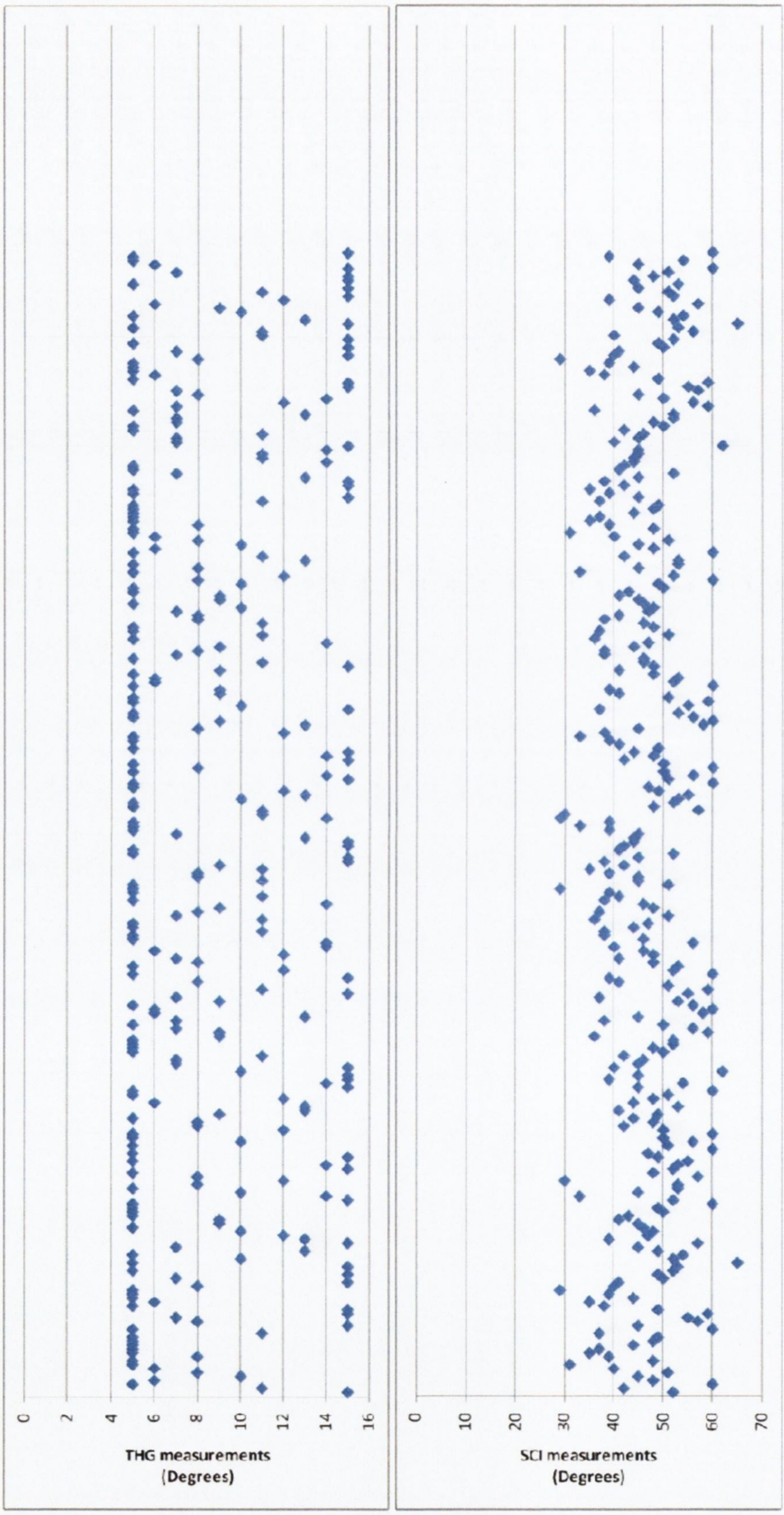


Figure 5-2 Distribution of measurements obtained for Transverse Horizontal Guidance and Sagittal Condylar Inclination.

Figures 5.3 & 5.4 demonstrate how the Transverse Horizontal Guidance settings followed a similar pattern for the different sagittal and vertical study groups. In all groups there tended to be a clustering of values towards the minimum value of 5° and to a lesser extent around the maximum value of 15°.

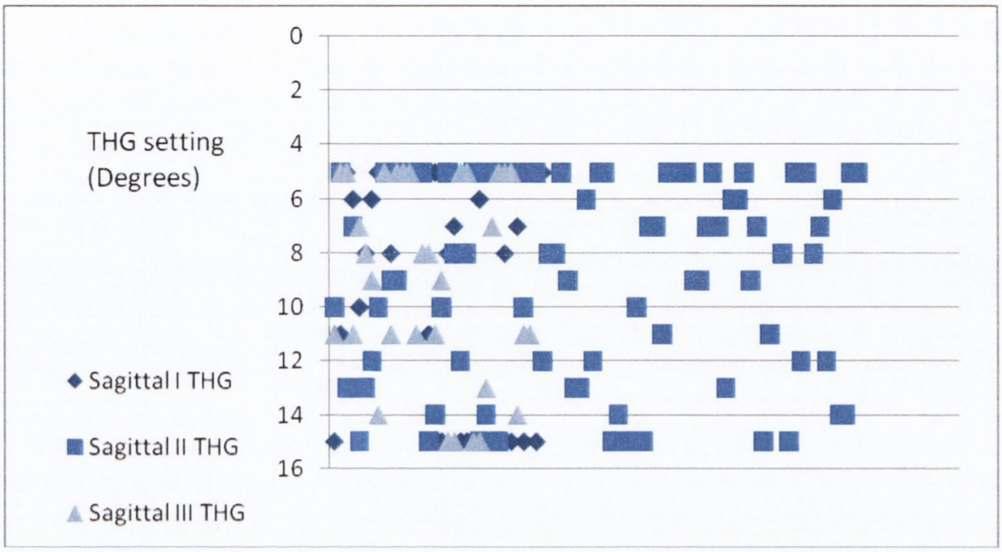


Figure 5-3 Scatter plot of data obtained for THG settings according to sagittal skeletal classification.

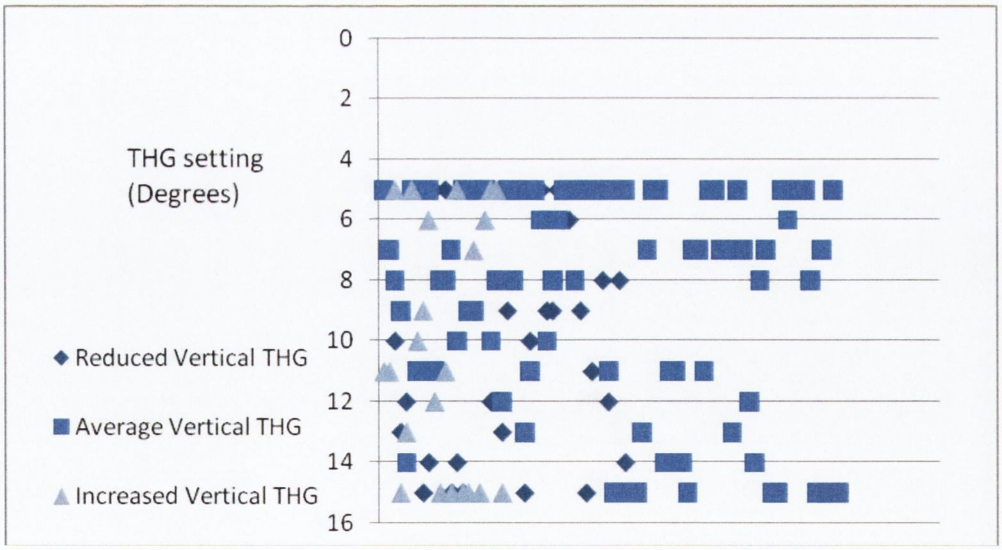


Figure 5-4 Scatter plot of data obtained for THG settings according to vertical skeletal classification.

5.5 Tables of articulator settings.

5.5.1 Articulator settings for entire study population.

Table 5.3 shows the means and standard deviations of the Transverse Horizontal Guidance, Sagittal Condylar Inclination and Immediate Side Shift values obtained for the entire sample population. Means and standard deviations were also calculated for the group of subjects who had a history of orthodontic treatment and for the group with no history of orthodontic treatment.

	THGright	THG left	SCI right	SCI left	ISS right	ISS left
All Study Groups	°	°	°	°	mm	mm
ALL (mean)	**8.35**	**9.20**	**46.50**	**47.04**	**0.11**	**0.06**
ALL (sd)	**3.43**	**4.03**	**7.62**	**7.60**	**0.19**	**0.12**
n=73						
Ortho (mean)	7.67	8.27	47.73	49.00	0.05	0.07
Ortho (sd)	2.92	3.49	7.16	7.20	0.08	0.07
n=14						
No-ortho (mean)	8.53	9.44	46.19	46.54	0.13	0.06
No-ortho sd	3.55	4.15	7.76	7.68	0.21	0.12
n=59						

Table 5-3 Articulator settings for all study groups. All horizontal and skeletal patterns represented. History of orthodontic treatment noted.

5.5.2 Articulator settings grouped according to underlying sagittal skeletal pattern.

Table 5.4 displays the means and standard deviations of the Transverse Horizontal Guidance, Sagittal Condylar Inclination and Immediate Side Shift values obtained for the group of subjects in the sagittal I group. Due to the similarity in values between those who had orthodontic treatment and those who had no orthodontic treatment the values were combined.

Sagittal I	THG right	THG left	SCI right	SCI left	ISS right	ISS left
	°	°	°	°	mm	Mm
ALL (mean)	7.19	9.44	44.13	46.38	0.12	0.09
ALL (sd)	3.06	4.56	7.46	9.03	0.14	0.18
n=16						

Table 5-4 Articulator settings for Sagittal I group. Results presented for all Sagittal I subjects. Sagittal I subjects with a history of orthodontic treatment and Sagittal I subjects with no history of orthodontic treatment are combined.

Table 5.5 displays the means and standard deviations of the Transverse Horizontal Guidance, Sagittal Condylar Inclination and Immediate Side Shift values obtained for the subjects in the sagittal II group. Due to the similarity in values between those who had orthodontic treatment and those who had no orthodontic treatment the values were combined.

Sagittal II	THG right	THG left	SCI right	SCI left	ISS right	ISS left
	°	°	°	°	mm	Mm
ALL (mean)	8.84	8.93	49.00	48.93	0.13	0.04
ALL (sd)	3.68	3.88	7.02	7.11	0.23	0.07
n=42						

Table 5-5 Articulator settings for Sagittal II group. Results presented for all Sagittal II subjects; Sagittal II subjects with a history of orthodontic treatment and Sagittal II subjects with no history of orthodontic treatment are combined.

Table 5.6 displays the means and standard deviations of the Transverse Horizontal Guidance, Sagittal Condylar Inclination and Immediate Side Shift values obtained for the group of subjects in the sagittal III group. Due to the similarity in values between those who had orthodontic treatment and those who had no orthodontic treatment the values were combined.

Sagittal III	THG right	THG left	SCI right	SCI left	ISS right	ISS left
	°	°	°	°	mm	mm
ALL (mean)	8.20	9.73	41.87	42.33	0.05	0.08
ALL (sd)	2.91	4.11	6.81	5.21	0.11	0.12
n=15						

Table 5-6 Articulator settings for Sagittal III group. Results presented for all Sagittal III subjects; Sagittal III subjects with a history of orthodontic treatment and Sagittal III subjects with no history of orthodontic treatment are combined.

5.5.3 Articulator settings grouped according to underlying vertical skeletal pattern.

Table 5.7 displays the means and standard deviations of the Transverse Horizontal Guidance, Sagittal Condylar Inclination and Immediate Side Shift values obtained for the group of subjects in the reduced vertical group. Due to the similarity in values between those who had orthodontic treatment and those who had no orthodontic treatment the values were combined.

Reduced Vertical	THG right	THG left	SCI right	SCI left	ISS right	ISS left
	°	°	°	°	mm	mm
ALL (mean)	9.24	8.38	48.10	48.19	0.12	0.05
ALL (sd)	4.21	3.43	8.40	8.41	0.16	0.08
n=20						

Table 5-7 Articulator settings for the reduced vertical group. Results are presented for all Reduced Vertical subjects. Values for Reduced Vertical subjects with a history of orthodontic treatment and Reduced Vertical subjects with no history of orthodontic treatment are combined.

Table 5.8 displays the means and standard deviations of the Transverse Horizontal Guidance, Sagittal Condylar Inclination and Immediate Side Shift values obtained for the group of subjects in the average vertical group. Due to the similarity in values between those who had orthodontic treatment and those who had no orthodontic treatment the values were combined.

Average Vertical	THG right	THG left	SCI right	SCI left	ISS right	ISS left
	°	°	°	°	mm	mm
ALL (mean)	7.43	9.31	44.50	45.69	0.12	0.06
ALL (sd)	2.64	4.13	6.62	7.27	0.22	0.11
n=42						

Table 5-8 Articulator settings for the reduced vertical group. Results are presented for all Average Vertical subjects. Results for Average Vertical subjects with a history of orthodontic treatment and Average Vertical subjects with no history of orthodontic treatment are combined.

Table 5.9 displays the means and standard deviations of the Transverse Horizontal Guidance, Sagittal Condylar Inclination and Immediate Side Shift values obtained for the group of subjects in the increased vertical group. Due to the similarity in values between those who had orthodontic treatment and those who had no orthodontic treatment the values were combined.

Increased Vertical	THG right	THG left	SCI right	SCI left	ISS right	ISS left
	°	°	°	°	mm	mm
ALL (mean)	10.18	10.36	51.09	50.00	0.08	0.07
ALL (sd)	3.63	4.74	7.60	6.62	0.13	0.18
n=11						

Table 5-9 Articulator settings for the increased vertical group. Results are presented for all Increased Vertical subjects. Values for Increased Vertical subjects with a history of orthodontic treatment and Increased Vertical subjects with no history of orthodontic treatment are combined.

Figure 5.5 summarises the observations made between the Transverse Horizontal Guidance and the Sagittal Condylar Inclination for each study group. The Transverse Horizontal Guidance and the Sagittal Condylar Inclinations are included for the sagittal I, II & III groups and for the reduced, average and increased vertical groups. The trend appears to be similar for the different study groups with the most marked difference arising between the Sagittal Condylar Inclination in the Sagittal II and Sagittal III groups.

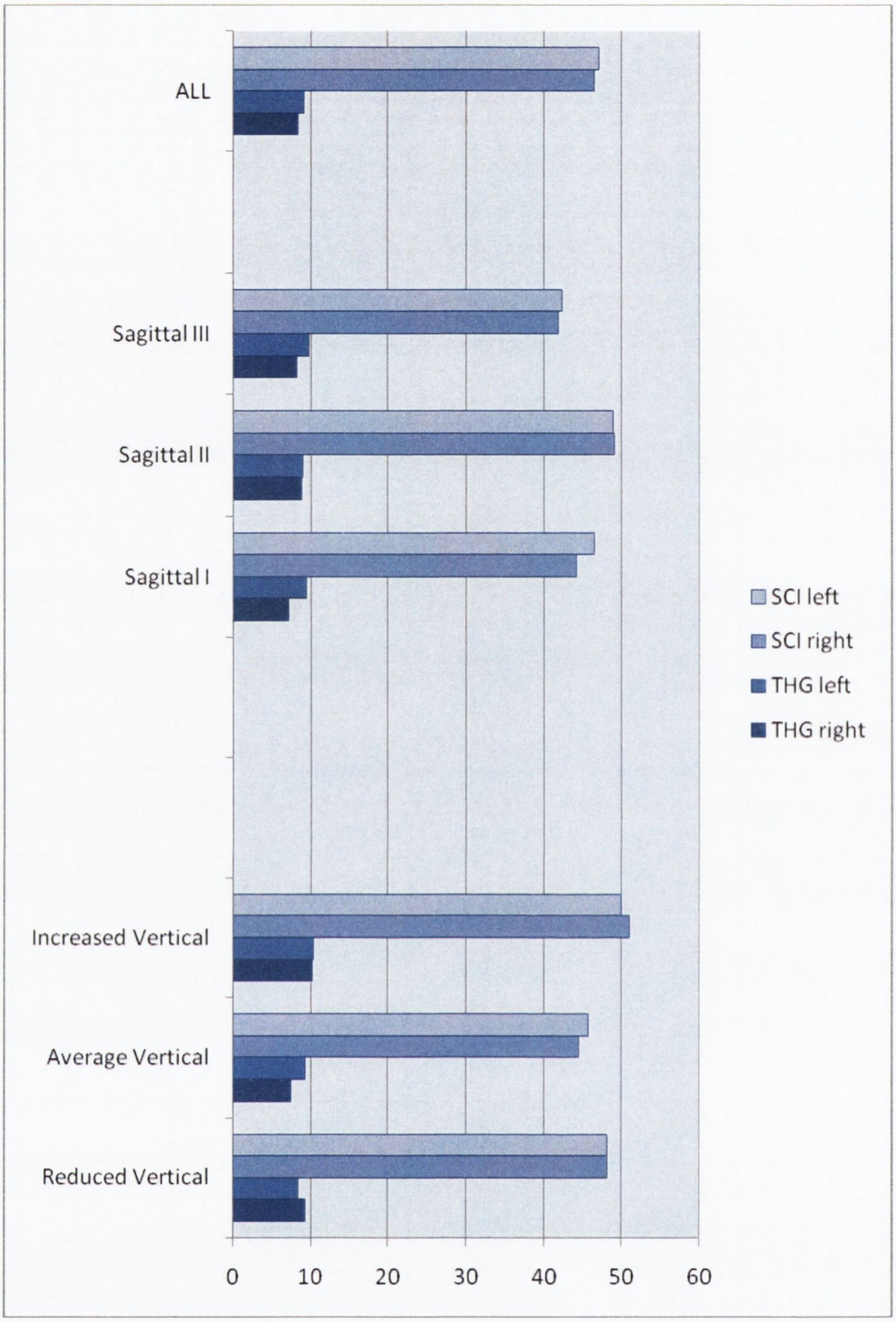


Figure 5-5 Graph demonstrating Transverse Horizontal Guidance and Sagittal Condylar Inclination for the entire study population. Right and left sides are included for comparison.

To ensure that there was no underlying effect from previous orthodontic treatment on the study results subjects' exposure to orthodontic treatment was recorded. The values obtained for Sagittal Condylar Inclination and Transverse Horizontal Guidance are graphically demonstrated in Figures 5.6 & 5.7. There appears to be a very close correlation which shows the apparent lack of effect of a positive history of orthodontic treatment upon the measurements recorded.

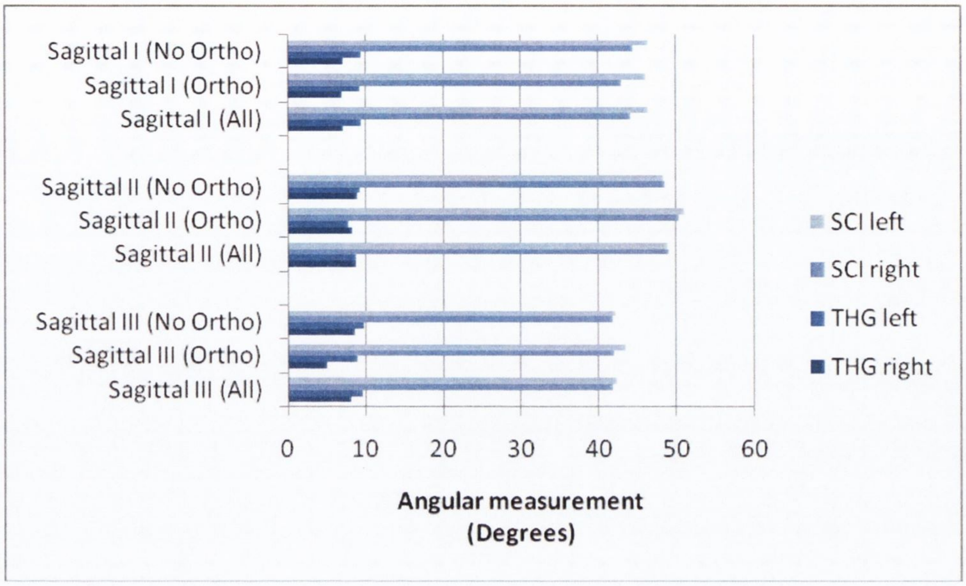


Figure 5-6 Graph demonstrating close correlation for angular measurements obtained for subjects having a history of orthodontic treatment and those with no history of orthodontic treatment. Sagittal study groups included.

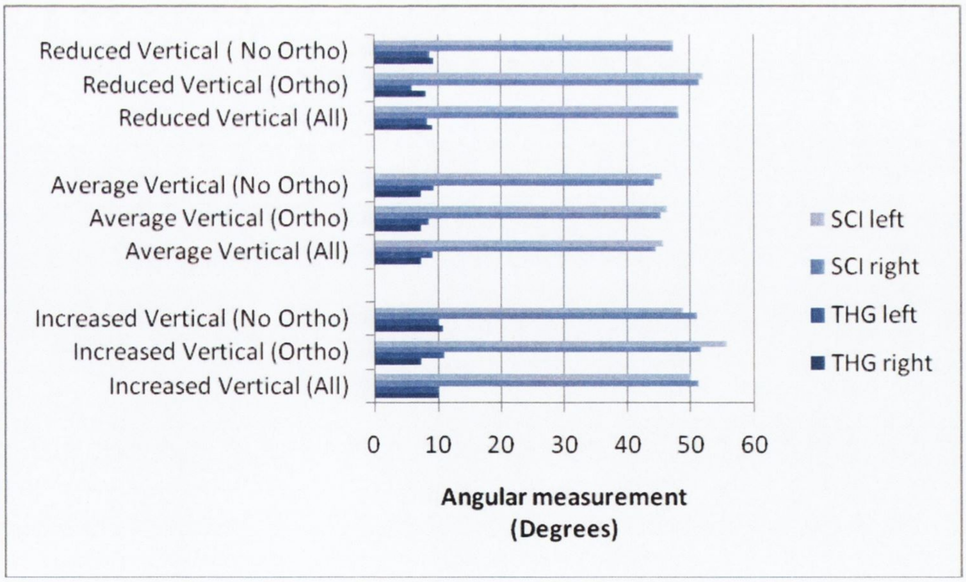


Figure 5-7 Graph demonstrating close correlation for angular measurements obtained for subjects having a history of orthodontic treatment and those with no history of orthodontic treatment. Vertical study groups included.

5.6 Reproducibility of reference position.

The reproducibility of the reference position for the entire study population and for the individual study groups is presented below. The Cadiax®Compact is capable of recording the position from which mandibular movements have originated. As a means of validating the reproducibility of the reference position multiple recordings of this position were obtained for each individual. This facility on the Cadiax®Compact records co-ordinate positions for the sagittal, vertical and transverse axes of movement within each mandibular condyle. The abbreviations used are:

DX right (anteroposterior)	Average deviation in the X co-ordinate at the right hand side condyle with repeated measures of the reference position.
DZ right (caudocephalad)	Average deviation in the Z co-ordinate at the right hand side condyle with repeated measures of the reference position.
DX left (anteroposterior)	Average deviation in the X co-ordinate at the left hand side condyle with repeated measures of the reference position.
DZ left (caudocephalad)	Average deviation in the Z co-ordinate at the left hand side condyle with repeated measures of the reference position.
DY (mediolaterally)	Average deviation in the Y co-ordinate with repeated measures of the reference position. One value is obtained for both condyles using this method.* **Only one value for DY is obtained as the axis is considered collinear and passes through both condyles.*

Table 5.10 summarises the results for the assessment of the reference position reproducibility for the entire study population. Again the data for those subjects who had a history of orthodontic treatment and those subjects with no history of orthodontic treatment are combined.

	DXR	DZR	DXL	DZL	DY
All Study Groups	mm	mm	mm	mm	mm
(mean)	**0.25**	**0.26**	**0.28**	**0.33**	**0.16**
(sd)	**0.32**	**0.30**	**0.30**	**0.32**	**0.14**
n=73					

Table 5-10 Mean and standard deviation of reference position co-ordinates for all study groups combined. Results for subjects with a history of orthodontic treatment and no history of orthodontic treatment are included for comparison.

The values obtained for the reproducibility study across the study groups are presented in tables 5.11-5.16

	DXR	DZR	DXL	DZL	DY
Sagittal I					
(mean)	**0.22**	**0.27**	**0.25**	**0.25**	**0.14**
(sd)	**0.32**	**0.43**	**0.27**	**0.21**	**0.10**
n=16					

Table 5-11 Mean and standard deviation of reference position co-ordinates for Sagittal I study group.

	DXR	DZR	DXL	DZL	DY
Sagittal II					
(mean)	**0.23**	**0.24**	**0.27**	**0.35**	**0.14**
(sd)	**0.23**	**0.23**	**0.30**	**0.37**	**0.12**
n=42					

Table 5-12 Mean and standard deviation of reference position co-ordinates for Sagittal II study group.

	DXR	DZR	DXL	DZL	DY
Sagittal III					
(mean)	**0.35**	**0.31**	**0.37**	**0.33**	**0.23**
(sd)	**0.50**	**0.33**	**0.33**	**0.25**	**0.18**
n=15					

Table 5-13 Mean and standard deviation of reference position co-ordinates for Sagittal III study group.

	DXR	DZR	DXL	DZL	DY
Reduced Vertical					
(mean)	**0.15**	**0.21**	**0.25**	**0.39**	**0.14**
(sd)	**0.16**	**0.20**	**0.26**	**0.44**	**0.16**
n=20					

Table 5-14 Mean and standard deviation of reference position co-ordinates for Reduced Vertical study group.

	DXR	DZR	DXL	DZL	DY
Average Vertical					
(mean)	**0.30**	**0.29**	**0.31**	**0.31**	**0.17**
(sd)	**0.38**	**0.36**	**0.28**	**0.26**	**0.14**
n=42					

Table 5-15 Mean and standard deviation of reference position co-ordinates for Average Vertical study group.

	DXR	DZR	DXL	DZL	DY
Increased Vertical					
(mean)	**0.25**	**0.26**	**0.26**	**0.28**	**0.14**
(sd)	**0.27**	**0.22**	**0.42**	**0.26**	**0.07**
n=11					

Table 5-16 Mean and standard deviation of reference position co-ordinates for Increased Vertical study group.

On close examination of the data obtained for the reproducibility study it was apparent that the measurements were not normally distributed. In order to facilitate further investigation of this data quartile analysis was undertaken. The results of this are presented below.

Sample Size	Class	**Quartile Analysis**						
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
20	Reduced	DXright	0.0	0.07	0.11	0.20	0.54	0.154	0.13
42	Average	DXright	0.01	0.06	0.195	0.295	1.79	0.300	0.24
11	Increased	DXright	0.0	0.055	0.18	0.32	0.78	0.253	0.198
73	**All**	DXright	0.0	0.055	0.155	0.278	1.79	0.251	0.223

Table 5-17 Quartile Analysis of DX right between different vertical study groups.

Sample Size	Vertical Class	Quartile Analysis							
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
20	Reduced	DX left	0.03	0.10	0.160	0.31	1.24	0.247	0.210
42	Average	DX left	0.02	0.07	0.215	0.45	1.36	0.308	0.375
11	Increased	DX left	0.01	0.035	0.070	0.22	1.43	0.259	0.185
73	**All**	DX left	0.01	0.07	0.185	0.375	1.43	0.283	0.305

Table 5-18 Quartile Analysis of DX left between different vertical study groups.

Sample Size	Sagittal Class	Quartile Analysis							
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
16	I	DXright	0.02	0.03	0.115	0.235	1.24	0.225	0.205
42	II	DXright	0.00	0.085	0.140	0.285	0.81	0.227	0.200
15	III	DXright	0.00	0.090	0.180	0.330	1.79	0.354	0.240
73	**All**	DXright	0.00	0.055	0.155	0.278	1.79	0.251	0.223

Table 5-19 Quartile Analysis of DX right between different sagittal study groups.

Sample Size	Sagittal Class	Quartile Analysis							
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
16	I	DX left	0.03	0.058	0.165	0.275	0.80	0.246	0.217
42	II	DX left	0.01	0.07	0.160	0.350	1.43	0.265	0.280
15	III	DX left	0.02	0.185	0.32	0.455	1.36	0.375	0.170
73	**All**	DX left	0.01	0.07	0.185	0.375	1.43	0.283	0.305

Table 5-20 Quartile Analysis of DX left between different sagittal study groups.

Sample Size	Vertical Class	Quartile Analysis							
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
20	Reduced	DZright	0.0	0.06	0.15	0.33	1.24	0.212	0.27
42	Average	DZright	0.01	0.07	0.135	0.32	1.71	0.286	0.25
11	Increased	DZright	0.04	0.13	0.17	0.42	0.73	0.265	0.29
73	**All**	DZright	0.0	0.07	0.16	0.35	1.71	0.262	0.28

Table 5-21 Quartile Analysis of DZ right between different vertical study groups.

Sample Size	Vertical Class	Quartile Analysis							
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
20	Reduced	DZ left	0.01	0.06	0.25	0.58	1.86	0.386	0.52
42	Average	DZ left	0.01	0.13	0.245	0.43	1.05	0.313	0.30
11	Increased	DZ left	0.02	0.16	0.24	0.29	1.00	0.281	0.13
73	**All**	DZ left	0.01	0.10	0.24	0.455	1.86	0.329	0.355

Table 5-22 Quartile Analysis of DZ left between different vertical study groups.

Sample Size	Sagittal Class	Quartile Analysis						
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
16	I	DZright	0.01	0.07	0.13	0.27	1.71	0.274	0.20
42	II	DZright	0.00	0.07	0.14	0.39	0.96	0.241	0.32
15	III	DZright	0.04	0.13	0.18	0.345	1.20	0.309	0.215
73	All	DZright	0.00	0.07	0.16	0.35	1.71	0.262	0.28

Table 5-23 Quartile Analysis of DZ right between different sagittal study groups.

Sample Size	Sagittal Class	Quartile Analysis							
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
16	I	DZ left	0.01	0.12	0.22	0.30	0.80	0.254	0.18
42	II	DZ left	0.01	0.11	0.24	0.46	1.86	0.354	0.35
15	III	DZ left	0.04	0.10	0.34	0.47	0.81	0.334	0.37
73	**All**	DZ left	0.01	0.10	0.24	0.46	1.86	0.329	0.36

Table 5-24 Quartile Analysis of DZ left between different sagittal study groups.

Sample Size	Vertical Class	Quartile Analysis							
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
20	Reduced	DY	0.00	0.05	0.08	0.15	0.63	0.141	0.10
42	Average	DY	0.00	0.05	0.15	0.26	0.51	0.172	0.21
11	Increased	DY	0.03	0.085	0.16	0.17	0.26	0.136	0.085
73	**All**	DY	0.00	0.05	0.12	0.22	0.63	0.158	0.17

Table 5-25 Quartile analysis of DY between different vertical study groups.

Sample Size	Sagittal Class	Quartile Analysis							
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
16	I	DY	0.02	0.075	0.11	0.18	0.41	0.138	0.105
42	II	DY	0.00	0.05	0.08	0.22	0.51	0.140	0.17
15	III	DY	0.02	0.10	0.21	0.29	0.63	0.229	0.19
73	**All**	DY	0.00	0.05	0.12	0.22	0.63	0.158	0.17

Table 5-26 Quartile analysis of DY between different sagittal study groups.

5.7 Correlation between orthodontists and restorative dentists in classifying underlying skeletal pattern.

A measure of the agreement between the orthodontists and prosthodontists on the basis of their classification of subjects accor5ing to skeletal classification from profile photographs was determined.

The following system was used: (for description see appendix)

Each subject was given three scores for skeletal classification and three scores for vertical classification by the group of prosthodontists. The same subject was given three further scores for skeletal classification and three scores for vertical classification by the group of orthodontists.

Absolute values for the differences in scores between the prosthodontists and orthodontists were obtained for sagittal and vertical characteristics. These figures were then summed together. The only possible outcomes of this process were 0, 2, 4 and 6.

O= Total agreement between all assessors.

2= Good agreement between all assessors.

4= Poor agreement between all assessors.

6= Total disagreement between all assessors.

A statistical programme was written which generated random scores for the six groups with a sample size of seventy-four. This process was repeated to obtain three thousand randomly selected data sets for seventy four subjects. The probability of obtaining an outcome on the basis of this simulation is listed below:

	Probability
0 (Total agreement)	0.1286
2 (Good agreement)	0.3456
4(Poor agreement)	0.3358
6 (Total disagreement)	0.19
	1

Table 5-27 Probability of obtaining a correlation value based on 3,000 repeated random samples of seventy four hypothetical subjects where each variable is measured six times.

Table 5.28 demonstrates the degree of agreement between the sagittal and vertical classification of subjects by the orthodontists and prosthodontists from facial profile photographs.

Score	Simulation*	Sagittal	Vertical
0 (Total agreement)	10	36	21
2 (Good agreement)	25	36	31
4(Poor agreement)	25	2	19
6 (Total disagreement)	14	0	3

Table 5-28 Correlation between orthodontists' and prosthodontists' classification of subjects according to sagittal and vertical skeletal pattern from profile photographs.*Simulation based on 3,000 random samples generated by computer programme.

From the results in table 5.28 it is apparent that there was a general trend for agreement between the orthodontists and prosthodontists in their allocation of subjects according to sagittal and vertical skeletal pattern. The agreement achieved 97% for good or total agreement in respect to sagittal skeletal pattern. The agreement was less but still high, reaching 70% for good or total agreement, between the orthodontists and prosthodontists when classifying subjects according to their vertical skeletal pattern.

5.8 Assessing differences in Sagittal Condylar Inclination between groups.

Examination of the measurements obtained for Sagittal Condylar Inclination for all study groups suggested that this data was normally distributed. The quartile analysis of the Sagittal Condylar Inclination measurements is presented below.

N=	Vertical Class	Quartile Analysis							
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
21	Reduced	SCI right	29	44	49	53	60	48.1	09.0
42	Average	SCI right	31	39.25	45.0	48.0	60.0	44.5	8.75
11	Increased	SCI right	39	47	52	55	65	51.1	08.0
73	**All**	**SCI right**	**29**	**41**	**47.5**	**51.75**	**65**	**46.5**	**10.75**

Table 5-29 Quartile Analysis of the measurements obtained for Sagittal Condylar Inclination (right hand side) for the study groups classified by vertical skeletal pattern.

N=	Vertical Class	Quartile Analysis							
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
20	Reduced	SCI left	33	41	48	55	60	48.2	14.0
42	Average	SCI left	29	41	45	50	62	45.7	09.0
11	Increased	SCI left	39	45	51	53.5	60	50.0	08.5
73	**All**	**SCI left**	**29**	**41**	**45.5**	**52**	**62**	**47.0**	**11.0**

Table 5-30 Quartile Analysis of the measurements obtained for Sagittal Condylar Inclination (left hand side) for the study groups classified by vertical skeletal pattern.

N=	Sagittal Class	Quartile Analysis							
		Measure	Min	Q1	Q2	Q3	Max	Mean	IQR
16	I	SCI right	31	38.5	44.5	48.25	60	44.1	9.75
42	II	SCI right	30	45	49	53	65	49.0	08.0
15	III	SCI right	29	38	40	46.5	56	41.9	08.5
73	**All**	**SCI right**	**29**	**41**	**47.5**	**51.75**	**65**	**46.5**	**10.75**

Table 5-31 Quartile Analysis of the measurements obtained for Sagittal Condylar Inclination (right hand side) for the study groups classified by sagittal skeletal pattern.

N=	Sagittal Class	Quartile Analysis							
		Measurement	Min	Q1	Q2	Q3	Max	Mean	IQR
16	I	SCI left	29	39.75	47.0	52.75	60	46.4	13.0
42	II	SCI left	36	44.5	48	53.5	62	48.9	09.0
15	III	SCI left	33	39	42	45.0	52	42.3	08.5
73	**All**	**SCI left**	**29**	**41**	**45.5**	**52.0**	**62**	**47.0**	**11.0**

Table 5-32 Quartile Analysis of the measurements obtained for Sagittal Condylar Inclination (left hand side) for the study groups classified by sagittal skeletal pattern.

Further assessment of the data suggests that the right and left hand sides are from the same normal distribution. The values obtained for the right and left sides were therefore combined and formal testing was undertaken using the Student's t-Test.

T Test between Groups	Sagittal I	Sagittal II	Sagittal III
Sagittal I		p<0.05	
Sagittal II			p<0.001
Sagittal III	N.S.		

Table 5-33 Results of Student's t-test between sagittal study groups comparing values for Sagittal Condylar Inclination.

T Test between Groups	Reduced Vertical	Average vertical	Increased vertical
Reduced Vertical		p<0.05	
Average Vertical			P< 0.01
Increased Vertical	N.S.		

Table 5-34 Results of Student's t-test between sagittal study groups comparing values for Sagittal Condylar Inclination.

In order to further investigate the relationship between sagittal and vertical skeletal pattern and Sagittal Condylar Inclination an ANOVA model was constructed. The data for Sagittal Condylar Inclination was further analysed using Dunnett's method using the sagittal I and average vertical groups as controls.

The results of this test are presented below.

SCI Values for the sagittal II group were significantly higher than those for the sagittal I group (p=0.02), whereas the sagittal I and sagittal III groups demonstrated similar values for Sagittal Condylar Inclination.

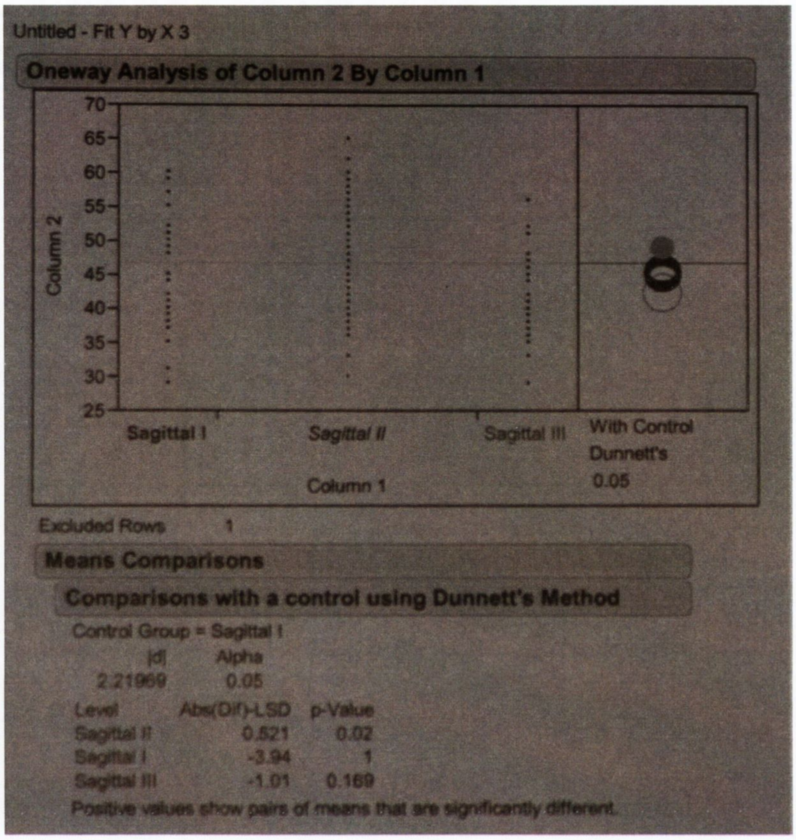


Figure 5-8 Comparison of SCI values for Sagittal study groups using Dunnett's Method.

The average vertical group was used as the control when comparing the SCI values according to vertical skeletal classification. The SCI values for the reduced vertical group almost demonstrated a statistically significant difference compared with the average group (p=0.058). The SCI values measured for the increased vertical group were highly statistically different (greater) than those of the average control group (p=0.005).

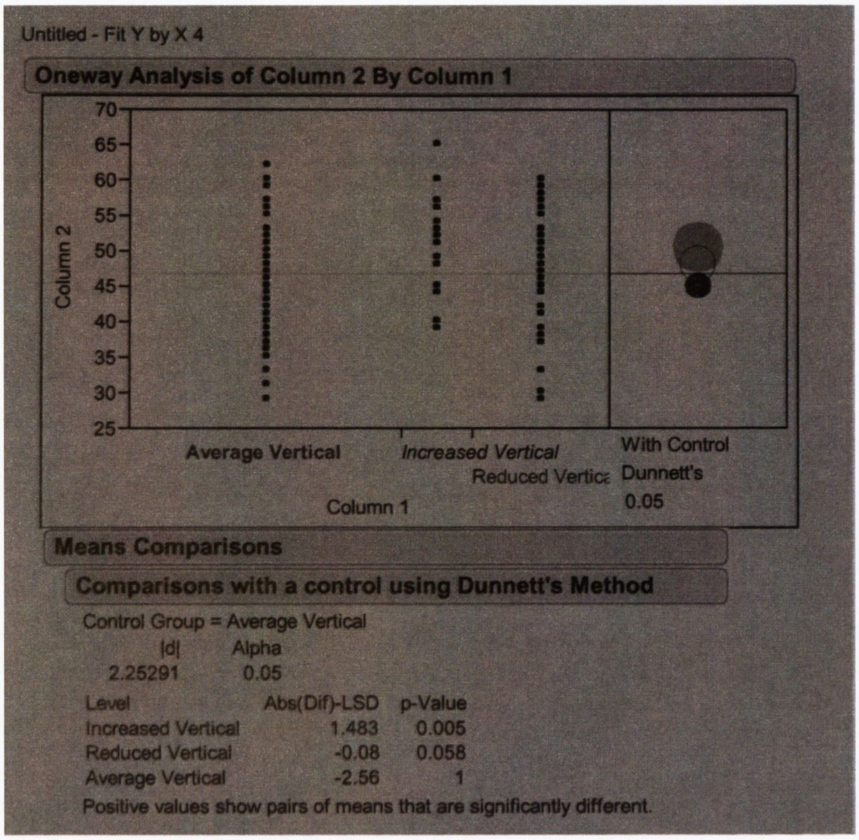


Figure 5-9 Comparison of SCI values for Vertical study groups using Dunnett's Method.

5.9 Assessing differences in Transverse Horizontal Guidance between Groups.

Analysis of the data recorded for Transverse Horizontal Guidance determined that these values were not normally distributed. In general the trend appeared to show a clustering of readings at the minimum and maximum values. Formal testing of this data was considered to be inappropriate on the basis that this clustering makes for great difficulty in specifying a distribution (and doing formal, parametric tests). Furthermore, the number of ties (repeated recordings of a similar value) prevents the application of meaningful non-parametric (rank-order statistics) methods.

N=	Class	Quartile Analysis							
		Measurement	Min	Q1	Q2	Q3	Max	Mean	IQR
16	Sagittal I	THG right	5.0	5.0	5.5	8.5	15.0	7.20	3.5
42	Sagittal II	THG right	5.0	5.0	8.0	12.0	15.0	8.84	7.0
15	Sagittal III	THG right	5.0	5.0	8.0	11.0	14.0	8.2	6.0
73	**All**	**THG right**	**5.0**	**5.0**	**8.0**	**11.0**	**15.0**	**8.35**	**6.0**

Table 5-35 Quartile analysis of the Transverse Horizontal Guidance for the sagittal groups. (Right hand side setting)

N=	Class	Quartile Analysis							
		Measurement	Min	Q1	Q2	Q3	Max	Mean	IQR
16	Sagittal I	THG left	5.0	5.0	7.5	15.0	15.0	9.4	10.0
42	Sagittal II	THG left	5.0	5.0	7.0	12.5	15.0	8.8	7.5
15	Sagittal III	THG left	5.0	5.0	11.0	13.5	15.0	9.7	8.5
73	**All**		**5.0**	**5.0**	**8.0**	**14.0**	**15.0**	**9.2**	**9.0**

Table 5-36 Quartile analysis of the Transverse Horizontal Guidance for the sagittal groups. (Left hand side setting)

N=	Vertical Class	Quartile Analysis							
		Measurement	Min	Q1	Q2	Q3	Max	Mean	IQR
20	Reduced	THG right	5.0	5.0	8.0	13.0	15.0	9.24	8.0
42	Average	THG right	5.0	5.0	7.0	9.0	14.0	7.43	4.0
11	Increased	THG right	5.0	7.5	11.0	12.5	15.0	10.2	7.5
73	**All**	**THG right**	**5.0**	**5.0**	**8.0**	**11.0**	**15.0**	**8.35**	**6.0**

Table 5-37 Quartile analysis of the Transverse Horizontal Guidance for the vertical groups. (Right Hand side setting)

N=	Vertical Class	Quartile Analysis							
		Measurement	Min	Q1	Q2	Q3	Max	Mean	IQR
20	Reduced	THG left	5.0	5.0	8.0	10.0	15.0	8.4	5.0
42	Average	THG left	5.0	5.0	7.0	14.0	15.0	9.31	9.0
11	Increased	THG left	5.0	5.5	11.0	12.5	15.0	10.4	7.0
73	**All**	**THG left**	**5.0**	**5.0**	**8.0**	**14.0**	**15.0**	**9.2**	**9.0**

Table 5-38 Quartile analysis of the Transverse Horizontal Guidance for the vertical groups. (Right Hand side setting)

The data presented in tables 5.35-5.38 demonstrate a difference in the Transverse Horizontal Guidance for the left and right hand sides for both the sagittal and vertical groups. The median value for both sides was 8° while the interquartile range was 6° for the right and 9° for the left hand sides respectively. On closer examination of the data it can be observed that the interquartile range was 5-11° for the right and 5-14° for the left. This suggests that recordings for THG on the left hand side consisted of a greater proportion of higher values than was observed for THG on the right hand side.

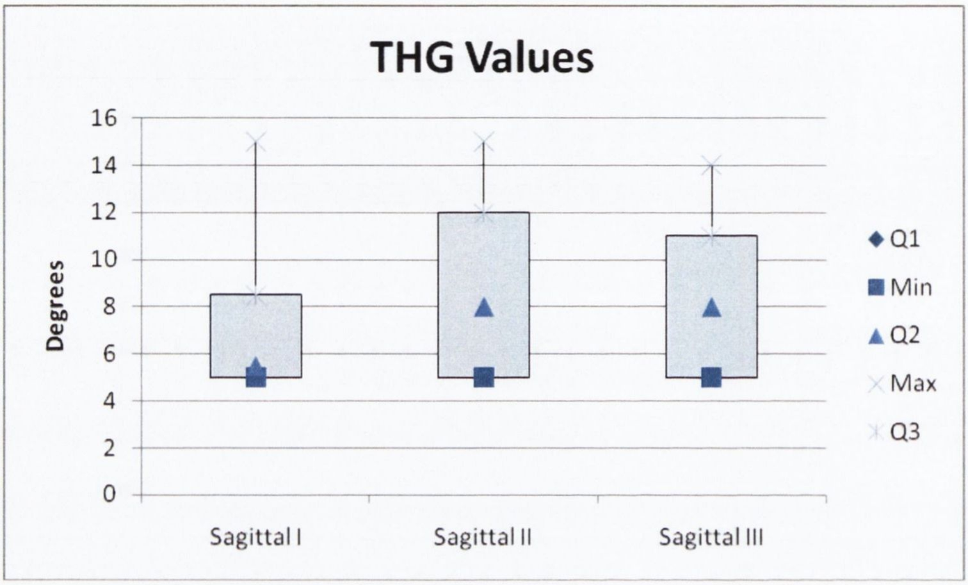


Figure 5-10 Box and whisker plot of Quartile analysis for Transverse Horizontal Guidance for Sagittal study groups. (Right hand side)

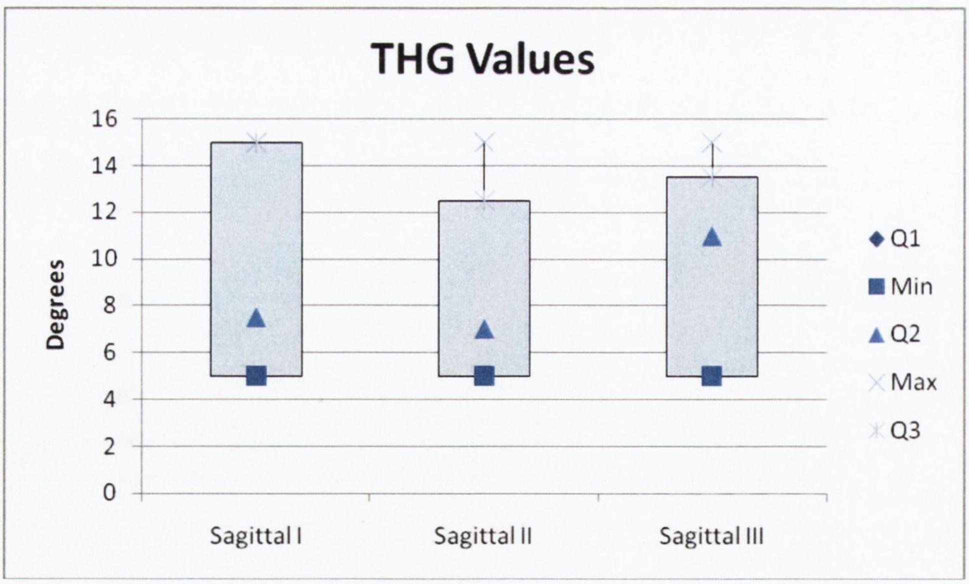


Figure 5-11 Box and whisker plot of Quartile analysis for Transverse Horizontal Guidance for Sagittal study groups. (Left hand side)

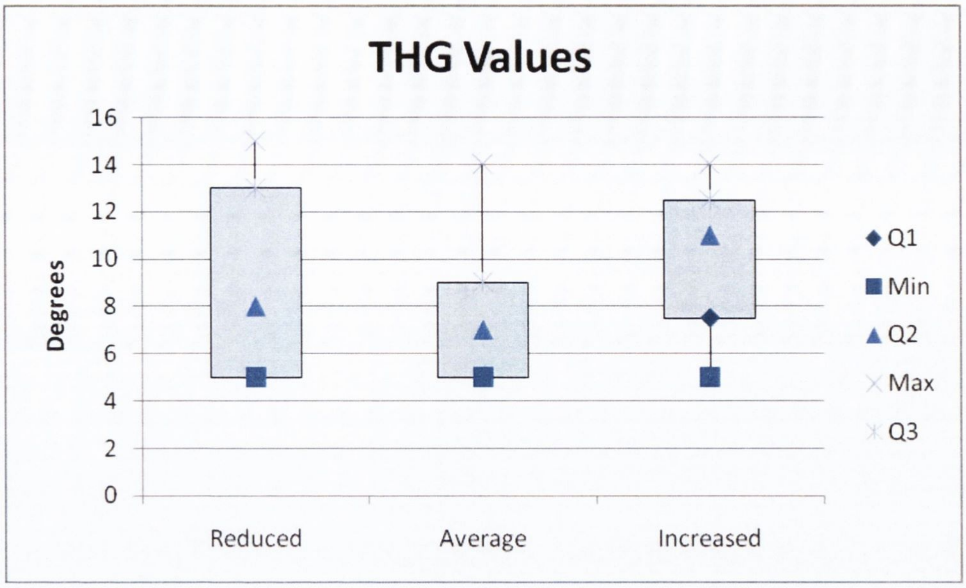


Figure 5-12 Box and whisker plot of Quartile analysis for Transverse Horizontal Guidance for vertical study groups. (Right hand side)

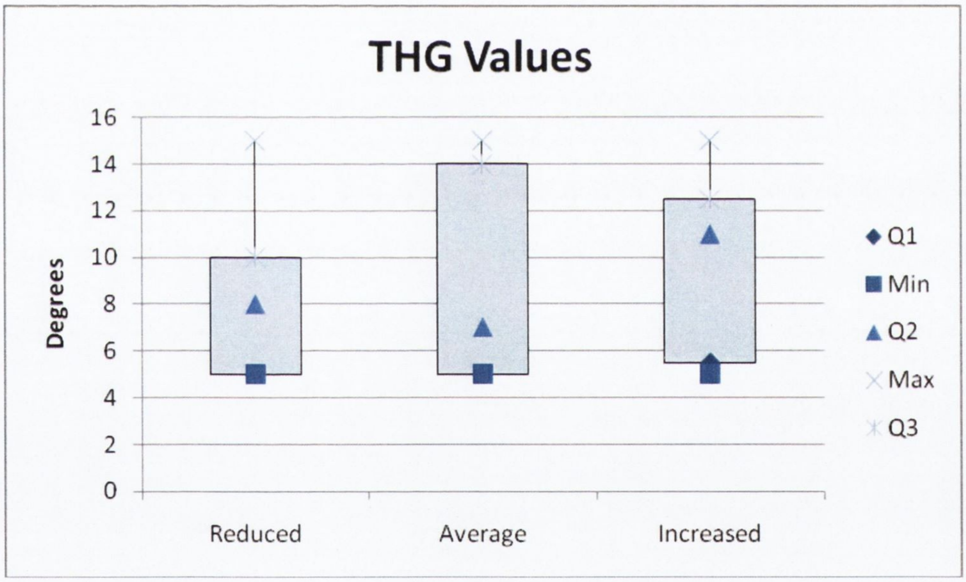


Figure 5-13 Box and whisker plot of Quartile analysis for Transverse Horizontal Guidance for vertical study groups. (Left hand side)

5.10 Assessment of Immediate Side Shift between groups.

The Immediate Side Shift was recorded for each subject. During recording of the data it was noted that there was a high percentage of values equal to zero. Tables 5.39-5.42 display the frequency distribution of the Immediate Side Shift values recorded.

Vertical Class	Sample Size	Number of Occurrences of Values 0 to 1.0 (ISS right)											
		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	
Reduced	20	11	3	2	2	2	1	-	-	-	-	-	
Average	42	23	9	5	2	-	1	-	-	-	1	1	
Increased	11	6	3	1	-	1	-	-	-	-	-	-	
All	**73**	**40**	**15**	**8**	**4**	**3**	**2**	**-**	**-**	**-**	**1**	**1**	

Table 5-39 Frequency distribution of ISS values for the study groups classified according to vertical skeletal pattern (right hand side).

Vertical Class	Sample Size	Number of Occurrences of Values 0 to 0.6 (ISS left)											
		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	
Reduced	20	13	6	1	1	-	-	-	-	-	-	-	
Average	42	29	6	4	1	2	-	-	-	-	-	-	
Increased	11	9	-	1	-	-	-	1	-	-	-	-	
All	**73**	**51**	**12**	**6**	**2**	**2**	**-**	**1**	**-**	**-**	**-**	**-**	

Table 5-40 Frequency distribution of ISS values for the study groups classified according to vertical skeletal pattern (left hand side).

Sagittal Class	Sample Size	Number of Occurrences of Values 0 to 1.0 (ISS right)											
		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	
I	16	6	5	3	1	-	1	-	-	-	-	-	
II	42	23	8	4	3	2	1	-	-	-	1	1	
III	15	11	2	1	-	1	-	-	-	-	-	-	
All	**73**	**40**	**15**	**8**	**4**	**3**	**2**	**-**	**-**	**-**	**1**	**1**	

Table 5-41 Frequency distribution of ISS values for the study groups classified according to sagittal skeletal pattern (right hand side).

Sagittal Class	Sample Size	Number of Occurrences of Values 0 to 0.6 (ISS left)											
		0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	
I	16	12	1	-	1	1	-	1	-	-	-	-	
II	42	30	9	3	1	-	-	-	-	-	-	-	
III	15	9	2	3	-	1	-	-	-	-	-	-	
All	**73**	**51**	**12**	**6**	**2**	**2**	**-**	**1**	**-**	**-**	**-**	**-**	

Table 5-42 Frequency distribution of ISS values for the study groups classified according to sagittal skeletal pattern (left hand side).

6. Discussion

6.1 Inclusion of subjects with a positive history of orthodontic treatment.

In the initial research protocol it was decided that subjects examined should not have a history of orthodontic treatment. This measure was felt necessary to exclude possible remodelling of the TMJ which may accompany orthodontic treatment. During the course of the study it became apparent that orthodontic treatment was quite common among the Dental Hospital student population. During the data collection subjects who had previous orthodontic treatment were included and a positive history of orthodontics was noted with the collated data.

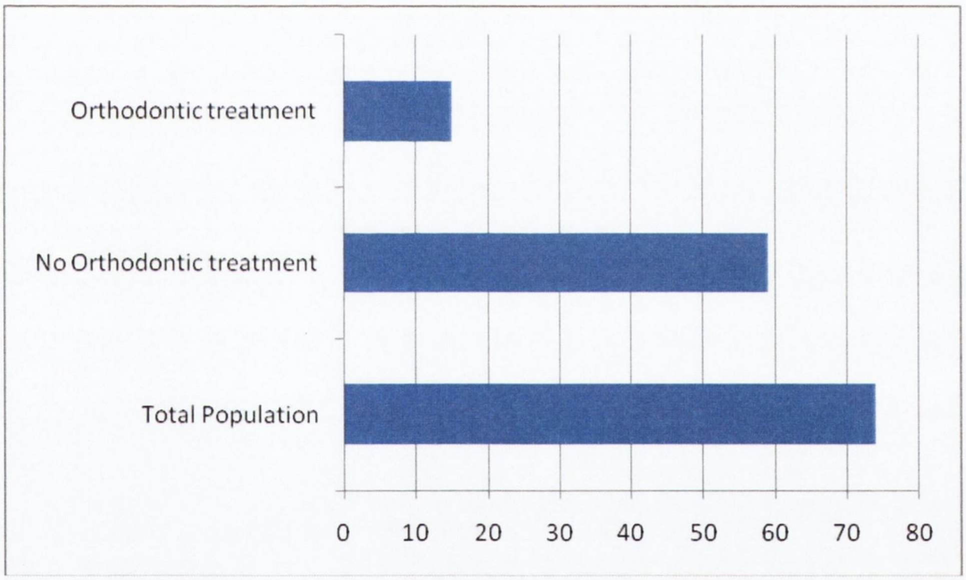


Figure 6-1 Distribution of subjects with positive history of orthodontic treatment.

A separate analysis of the data excluding those who had orthodontic treatment was undertaken to examine a possible influence on the results.

Table 6.4 describes the data obtained for the Transverse Horizontal Guidance, the Sagittal Condylar Inclination and the

Immediate Side Shift for those subjects with a positive history of orthodontic treatment and those without. The influence of orthodontics on the results was considered insignificant. Due to the relatively small number of subjects with a positive history of orthodontic treatment and the similarity between measurements it was decided to group all data together for analysis.

	THG right	THG left	SCI right	SCI left	ISS right	ISS left
All Study Groups	°	°	°	°	mm	mm
ALL (mean)	**8.35**	**9.20**	**46.50**	**47.04**	**0.11**	**0.06**
ALL (sd)	**3.43**	**4.03**	**7.62**	**7.60**	**0.19**	**0.12**
n=73						
Ortho (mean)	7.67	8.27	47.73	49.00	0.05	0.07
Ortho (sd)	2.92	3.49	7.16	7.20	0.08	0.07
n=14						
No-ortho (mean)	8.53	9.44	46.19	46.54	0.13	0.06
No-ortho sd	3.55	4.15	7.76	7.68	0.21	0.12
n=59						

Table 6-1 Articulator settings for all study groups. All horizontal and skeletal patterns represented. History of orthodontic treatment noted.

6.2 Combining data for Class II division 1 & 2 BSI classification.

During the initial data recording the incisor classification was noted. It was planned that Class II division 1 and Class II division 2 patients would be considered separately. The low number of Class II division 2 subjects in the study precluded this; (only three subjects demonstrated a BSI Class II division 2 incisor classification) therefore it was decided to amalgamate the data for the class II subjects. The British Standards incisor classification system[31] does not take into account the skeletal pattern and it was the influence of the skeletal pattern upon mandibular movement which was being assessed in this study. The decision to pool the data for Class II division 1 and Class II division 2 subjects was further influenced by the work of Katsavrias[17]. This morphometric study assessed the condyle and fossa shape using corrected tomograms. Katsavrias demonstrated that Class III patients had statistically significant differences in condyle and fossa shape (flatter and shallower) compared with Class II cases. There was no significant difference between Class II division 1 and Class II division 2 with respect to condyle and fossa shape. Thus it was felt appropriate to group the Class II division 1 and 2 subjects together for the present study.

6.3 Use of soft tissue profile as surrogate means of skeletal classification.

For ethical reasons radiographic assessment could not be undertaken and soft tissue profile was used as a surrogate measure of the underlying skeletal pattern. While this may have some limitations[106] it is clinically valid and routine use of lateral cephalometric radiographs for prosthodontic diagnosis and treatment planning is not commonplace[107].

The classification of subjects according to skeletal pattern involved assessment of profile photographs by senior orthodontic and prosthodontic staff from the Dublin Dental School and Hospital. This method of evaluation has been analysed by Kuyl et al.[106] and has been shown to be more consistent for sagittal profile than for vertical profile. In Kuyl's study orthodontists, irrespective of degree of training, were more consistent in assessing soft tissue profile than general dentists. For this reason senior orthodontic and prosthodontic staff were chosen to evaluate the profile photographs of the subjects. The agreement between the 2 groups of assessors was determined using a random samples method. This compared results for sagittal and vertical classification from all of the assessors for each of the study participants with a computer generated random allocation on the basis of three thousand repeated trials for seventy four subjects. For full description see appendix 8.10.

Score	Simulation*	Sagittal	Vertical
0 (Total agreement)	10	36	21
2 (Good agreement)	25	36	31
4(Poor agreement)	25	2	19
6 (Total disagreement)	14	0	3

Table 6-2 Correlation between orthodontists' and prosthodontists' classification of subjects according to sagittal and vertical skeletal pattern from profile photographs.*Simulation based on 3,000 random samples generated by computer programme.

From the results in table 6.2 it is apparent that there was a general trend for agreement between the orthodontists and prosthodontists in their allocation of subjects according to sagittal and vertical skeletal pattern. The agreement achieved 97% for good or total agreement in respect to sagittal skeletal pattern. The agreement was less but still high, reaching 70% for good or total agreement, between the orthodontists and prosthodontists when classifying subjects according to their vertical skeletal pattern. This is in agreement with Kuyl et al[106] who also demonstrated a trend for greater accuracy in assessment of sagittal as opposed to vertical characteristics. During the allocation process no guidance was given to the assessors regarding sagittal or vertical classification. From the results it was apparent that the two groups were more consistent in determining sagittal classification and had some difficulty in agreeing on vertical skeletal pattern. Without strict criteria for vertical classification this result could be expected and this could be considered a limitation of the present study.

In their study Kuyl et al used a Duplo-test to observe the agreement between three groups of orthodontists and one group of general dentists in their ability to repeatedly score the same sagittal and vertical characteristics for a group of patients. Photographs of the same patients were again observed after a four week interval. The degree of agreement between groups was judged on the basis of the percentage of duplicated scores for each assessor.

A different approach to determining the correlation between the groups of assessors was used in the present study. A single score for sagittal classification and a single score for vertical classification was obtained from each assessor for each subject. In order to make comparison between the groups the following method was used: (for extended description see appendix 8.10)

Each subject was given three scores for skeletal classification and three scores for vertical classification by the group of prosthodontists. The same subject was given three further scores for skeletal classification and three scores for vertical classification by the group of orthodontists.

Absolute values for the differences in scores between the prosthodontists and orthodontists were obtained for sagittal and vertical characteristics. These figures were then summed together. The only possible outcomes of this process were 0, 2, 4 and 6.

O= Total agreement between all assessors.

2= Good agreement between all assessors.

4= Poor agreement between all assessors.

6= Total disagreement between all assessors.

A statistical programme was written which generated random scores for the six groups with a sample size of seventy-four. This process was repeated to obtain three thousand randomly selected data sets for seventy four subjects. The probability of obtaining an outcome on the basis of this simulation is listed below:

	Probability
0 (Total agreement)	0.1286
2 (Good agreement)	0.3456
4(Poor agreement)	0.3358
6 (Total disagreement)	0.19
	1

Table 6-3 Probability of obtaining a correlation value based on 3,000 repeated random samples of seventy four hypothetical subjects where each variable is measured six times.

This system was considered a more appropriate test of correlation between groups in determining skeletal classification. The method involving duplicated scores essentially tests the ability of an operator to reproduce the same score on two occasions and this forms the basis for comparison between groups of assessors. Our method calculated the agreement between a group of assessors at one period in time and reports on the degree of correlation within the group. The weakness of this system is that it does not indicate the relative contribution of scores from orthodontists or prosthodontists in borderline cases.

Incisor relationship was recorded according to the British Standards Incisor Classification system[31] and molar relationship according to Angle's Classification[29] during the clinical recording session. This data was considered for inclusion in allocating subjects according to skeletal pattern. It was decided that this additional information may have biased the allocation of subjects into study groups and would also further complicate the grouping procedure. The principal aims of the study were to investigate the effect of skeletal pattern on mandibular movement and therefore the dental relationship was not included.

6.4 Allocation of subjects into study groups.

The subjects were allocated into study groups based on their sagittal and vertical skeletal patterns. Table 6.3 shows the distribution of participants into study groups.

	Number of Subjects		Number of Subjects
Sagittal I	16	**Reduced Vertical**	20
Sagittal II	42	**Average Vertical**	42
Sagittal III	15	**Increased Vertical**	11
Total	73	Total	73

Table 6-4 Allocation of subjects to study groups.

The distribution of skeletal patterns did not follow the frequency expected for a random sample of Irish patients. The study sample population was a sample of convenience where subjects with underlying skeletal patterns were actively sought. The frequency of sagittal II and sagittal III was higher than would have been observed in a random sample. The prevalence of Class II division 1 malocclusions is thought to be between 15-20% in a Caucasian population.[38] Class II division 2 are estimated to be present in approximately 10% of a Caucasian population. It may be associated with a mild class II skeletal pattern or in some cases a skeletal I or mild skeletal III pattern can be observed.[39] Class III malocclusions are the least common observed in a Caucasian population, with an estimated prevalence of approximately 3%. The results of this study were aimed at a specific population and for this reason we observed a greater percentage of patients with skeletal discrepancies than would generally be expected.

6.5 The use of a 10mm condylotrack recording where available.

In selecting the transverse and Sagittal Condylar Inclination values for each subject from the pantographic recordings it was decided that the 10mm recording would be used for comparison. Chang[99] demonstrated that over this distance the Cadiax® Compact was most reliable. In situations where a 10 mm recording was not available as the condyle had not travelled this distance the next reading (5 mm of translation) was used as this is deemed to be more accurate than 3 mm readings[99].

During compilation of the recorded data for statistical assessment it was observed that for some subjects a 10 mm recording was available bilaterally, for some a 10 mm recording was only obtained unilaterally while for others only 5 mm recordings were available bilaterally. This suggests that for some subjects examined the condyle translated further on one side or both sides did not translate as far as in other cases. In obtaining the recordings for sagittal and transverse articulator settings a trend was observed whereby the 10mm recording was significantly lower than the 5mm recording for Sagittal Condylar Inclination for the same subject figure 6.2.

CADIAX® Curves

	Protrusion		Mediotrusion right		Mediotrusion left	
	SCI right	SCI left	S C I	T C I	S C I	T C I
1st	46.2°	48.6°	38.6°	3.6°	49.0°	18.9°
2nd	46.2°	52.8°	43.6°	15.7°	55.3°	22.3°
3rd	45.5°	52.8°	43.8°	17.4°	55.0°	23.6°
4th	44.7°	51.8°	43.6°	16.2°	54.4°	23.4°
5th	43.5°	50.6°	42.7°	14.5°	52.7°	22.3°
6th	42.4°	48.8°	42.0°	13.9°	50.9°	21.4°
8th	40.2°	45.4°	39.0°	12.9°	47.1°	19.0°
10th	37.2°	42.1°	36.6°	12.1°	43.0°	17.3°
14th			31.8°	12.9°	35.7°	15.4°

	Retrusion	
-1.	18.6°r	78.5°r
-2.		

Sagittal Condylar Guidance Denar® Mark II

Right			Left		
3rd mm	5th mm	10th mm	3rd mm	5th mm	10th mm
46°	45°	41°	52°	52°	46°

Transverse Condylar Guidance Denar® Mark II

	Right			Left		
	3rd mm	5th mm	10th mm	3rd mm	5th mm	10th mm
Angle	15°	15°	13°	15°	15°	15°
ISS	0.0	0.0	0.0	0.0	0.0	0.0

ISS Threshold: 0.5

Figure 6-2 Articulator settings from a study subject providing sagittal condylar guidance settings for 10mm condylotrack distance bilaterally.

The manufacturers claim that the Cadiax® Compact records data over the range of translation and calculates the reading based on a numerical average for the distance travelled[85]. Rather than only using 5mm readings for all subjects the following approach was used; where only 5mm readings were available bilaterally these were used for statistical analysis, in cases where a 10mm reading was available for one side and a 5mm reading was available for the other the 10mm reading was recorded bilaterally if the angles were exhibiting a similar pattern of reduction with distance travelled (Figure 6.3). In cases where there was asymmetry for the angular readings the 5mm and the 10mm values were entered for analysis as obtained from the Gamma Dental Software® version 3 package. This process was considered by the authors to be the most appropriate as it most accurately reflected the clinical management of such readings for Sagittal Condylar Inclination.

CADIAX® Curves

	Protrusion		Mediotrusion right		Mediotrusion left	
	SCI right	SCI left	S C I	T C I	S C I	T C I
1st	59.9°	54.2°	62.0°	5.6°	52.5°	-16.8°
2nd	59.9°	55.1°	61.1°	-1.7°	53.4°	-8.9°
3rd	59.1°	54.2°	59.9°	-1.9°	52.7°	-5.6°
4th	57.9°	53.0°	58.1°	-2.7°	51.7°	-4.1°
5th	55.9°	51.4°	56.6°	-2.1°	50.6°	-2.2°
6th	53.9°	49.7°	54.8°	-1.3°	48.8°	0.4°
8th	49.6°	45.5°	50.5°	-0.3°	44.2°	4.4°
10th	43.7°		45.4°	0.8°	40.1°	6.4°
14th			34.9°	3.0°		

	Retrusion	
-1.	29.1°d	
-2.		

Sagittal Condylar Guidance Denar® Mark II

Right			Left		
3rd mm	5th mm	10th mm	3rd mm	5th mm	10th mm
60°	58°	49°	55°	53°	

Transverse Condylar Guidance Denar® Mark II

	Right			Left		
	3rd mm	5th mm	10th mm	3rd mm	5th mm	10th mm
Angle	5°	5°	5°	5°	5°	5°
ISS	0.1	0.1	0.1	0.0	0.0	0.0

ISS Threshold: 0.5

Figure 6-3 Articulator settings from a study subject providing sagittal condylar guidance settings for 10mm condylotrack distance for right and 5mm condylotrack distance for left.

6.6 Selection of the Cadiax® Compact for recording mandibular movement.

Petrie et al.[100] called into question the reproducibility of the Cadiax®Compact. They compared Pantographic Reproducibility Index (PRI) scores obtained with a mechanical Denar® pantograph to those obtained with a Cadiax®Compact. The Cadiax® Compact did not appear to be reproducible over 2 different clinical recording sessions as determined by PRI scores. Nevertheless, further *in-vitro* and *in-vivo* studies assessing the accuracy of the Cadiax®Compact have deemed it to be suitably reproducible for clinical use [98, 99, 101]. Bernhardt et al.[101] used the Cadiax® Compact and demonstrated an interclass correlation coefficient of 0.71 for repeated measures when an arbitrary hinge axis was utilised demonstrating good reproducibility. Petrie et al.[100] offered some suggestions as to why their results were inferior when using the Cadiax® Compact. They observed that without a central bearing point it was difficult for their subjects to attain a reproducible centric relation position. With the Denar®pantograph all subjects were able to demonstrate a reproducible centric relation position while 30% could not when the Cadiax® Compact system was used. It was also conceded that the fixation of the mandibular clutch to the mandibular teeth with a polyvinyl siloxane bite registration material may not be entirely rigid and this may have also affected their results. For the purposes of Petrie's study Blu-Mousse was used to provisionally secure the mandibular clutches to the mandibular teeth (Blu-Mousse Super-Fast; Parkell, Farmingdale, NY).

6.7 Selection of the Denar®Mark II articulator settings for analysis.

The Cadiax® Compact system used in this study was capable of providing articulator settings for 25 articulators. This study aimed to examine the effect of skeletal pattern on mandibular movement and ultimately on articulator settings. It was decided to use the results for the Denar® Mark II for analysis as with this articulator settings for Sagittal Condylar Inclination and Transverse Horizontal Guidance can be adjusted along with Immediate Side Shift. Other articulator settings generated by the Cadiax® Compact and the Gamma Dental Software® version 3 package do not allow for changes in the transverse settings or do not give numerical angulation values. Chang[99] has also demonstrated that the Cadiax® Compact can reliably reproduce the movements made with the Denar® Mark II.

6.8 The clinical significance of variation in Immediate Side Shift in articulator settings.

The significance if Immediate Side Shift setting in the programming of an articulator has been noted by previous authors[67, 76, 77, 108]. Lundeen[67] suggested that a 1:1 relationship exists between the movement of the condyle in a lateral direction and its influence on the first mandibular molar. Gibbs et al[109] assessed the effects of alterations in the condylar inclination and incisal guidance at the level of the first molar. On the basis of their research they suggested that patients with average side shift values (approximately 0.75mm) could have suitable restorations made on semi-adjustable articulators without the need for adjusting eccentric interferences intraorally.

Wachtel and Curtis[76, 77] assessed the effect of Immediate Side Shift settings on tooth movement in semi-adjustable adjustable articulators. The Denar® Mark II was evaluated in this study. The authors observed the effect of altered Immediate Side Shift on cusp movement at the level of the first molar in semi-adjustable articulators with and without the capacity for Immediate Side Shift adjustment. They concluded that when the ISS was <0.75 mm the semi-adjustable articulators tested were able to accurately reproduce mandibular movement. In the presence of Immediate

Side Shift of 2 mm or more a semi-adjustable articulator was unreliable and the use of a fully adjustable articulator was recommended.

6.9 Observations of Immediate Side Shift values between groups.

The measurements of Immediate Side Shift were recorded during the clinical recording session. The Cadiax® Compact imposed a threshold value of 0.5mm for Immediate Side Shift when used in the setting of the Denar® Mark II articulator. Measurements below this value may be discarded as clinically irrelevant. The data obtained for Immediate Side Shift for all study groups demonstrated a dramatic clustering about zero.

Forty of seventy three (55%) values for right side Immediate Side Shift and fifty one of seventy three (70%) values for left side Immediate Side Shift were zero. This may be due to a lack of sensitivity of the recording instrument or may suggest a general lack of Immediate Side Shift within the subjects examined. Given that the inclusion criteria required subjects to have healthy TMJs and the fact that the majority of the subjects were young adults this result could have been expected. Of the 73 subjects who provided mandibular movement data 25 were adolescents or young adults from the regional orthodontic units, 42 were undergraduate dental students and the remaining 6 were patients under prosthodontic treatment.

Of the 156 Immediate Side Shift recordings in total only five measured 0.5 mm or greater. No observations can be made except for a clustering around zero and a high predominance of Immediate Side Shift values less than 0.5 mm for all study groups.

6.10 Reproducibility of the reference position.

Mandibular movements were demonstrated to and rehearsed by subjects prior to the recording procedure. To determine the reproducibility of the reference position the CPM function of the Cadiax® Compact was used. This allows for the reading of multiple positions and gives a numerical value for any differences observed. After subjects had completed the mandibular movements they were asked to protrude, open and close, and protrude again. On completion of each movement the subjects returned their mandible to the reference position. This procedure allowed for additional recordings of the reference position. Before any movements were recorded the position of the hinge axis relative to the recorded reference position was observed. If there was an obvious deviation (>0.7mm) the subject was asked to return the mandible to the reference position[105]. In cases where this did not improve the mandibular position a new reference position was recorded prior to any further mandibular movement recordings. To allow for such errors in reprodicibility of the reference position multiple readings were obtained for evaluation. The Cadiax® Compact CPM (Condylar Position Measurement) function is capable of recording the position from which mandibular movements have originated. As a means of validating the reproducibility of the reference position multiple recordings of this position were obtained for each individual. This facility on the Cadiax® Compact records co-ordinate positions for the sagittal, vertical and transverse axes of movement within each mandibular condyle.

The abbreviations used are:

DX right (anteroposterior)	Average deviation in the X co-ordinate at the right hand side condyle with repeated measures of the reference position.
DZ right (caudocephalad)	Average deviation in the Z co-ordinate at the right hand side condyle with repeated measures of the reference position.
DX left (anteroposterior)	Average deviation in the X co-ordinate at the left hand side condyle with repeated measures of the reference position.
DZ left (caudocephalad)	Average deviation in the Z co-ordinate at the left hand side condyle with repeated measures of the reference position.
DY (mediolaterally)	Average deviation in the Y co-ordinate with repeated measures of the reference position. One value is obtained for both condyles using this method.* **Only one value for DY is obtained as the axis is considered collinear and passes through both condyles.*

Table 6-5 Abbreviations used for the co-ordinate system to describe the reproducibility of the reference position.

The data obtained from these measurements were not normally distributed and this was further compounded by differences between right and left sides.

Quartile analysis was undertaken to observe differences between groups. The median values for DX ranged from 0.11 mm (reduced vertical group: right side) to 0.32 mm (sagittal III group: left side). The median values for DZ ranged from 0.13 mm (sagittal I group: right side) to 0.34 mm (sagittal III group: left side). The median values of DY ranged from 0.08 mm (reduced vertical group) to 0.21 mm (sagittal III group).

A trend was observed whereby the median value for difference in co-ordinate measurements was greater in the sagittal III population compared with the sagittal I or II groups.

Evaluation of the quartile analysis suggested that for all groups the distribution of measurements was not normally distributed. Measurements for reference position reproducibility, based upon a difference in co-ordinate position, were most frequent at the lower values. Mean results were characteristically higher than median values due to the presence of isolated high values. This, in addition to differences between left and right sides, makes clinically relevant comparison between groups impossible. The results do however suggest that a high degree of reproducibility for the reference position was observed for all groups.

From the results it was impossible to predict subjects with reproducibility difficulties on the basis of their horizontal or vertical skeletal pattern.

6.11 The clinical significance of variation in Transverse Horizontal Guidance and Sagittal Condylar Inclination in articulator settings.

The null hypothesis for this research project is that there is no difference in articulator settings between groups of patients demonstrating different skeletal patterns. The variation between a patient's condylar guide inclination and that of an average value must be addressed. Satisfactory restorations can be constructed in situations where average values are utilised, particularly in the presence of a mutually protected occlusal scheme. It is possible that errors may be introduced by having the articulator set to an inappropriate condylar inclination. Dos Santos et al.[91] described these errors. Having the condylar guidance higher in the articulator than the patient's condylar inclination could result in the provision of restorations with either protrusive and/or lateral interferences. Alternatively, setting the articulator too low may result not only in flat occlusal morphology but may also indicate interferences in the articulator which are not present in the patient. Craddock[110] evaluated the effect of changing the sagittal condylar guidance on the occlusal contacts. He estimated that an increase of 10° would separate the molar teeth by 0.5 mm while a decrease of 10° would bring the mandible 0.5 mm closer. Craddock suggested a +/- 5° change in Sagittal Condylar Inclination would effect a +/- 0.25 mm change in the molar region. Weinberg[104] used average values for a hypothetical average patient and mathematically calculated the inherent errors in using a semi-adjustable articulator. He suggested that a 9° error (decrease) in the protrusive condylar inclination (Sagittal Condylar Inclination) resulted in an error in the magnitude of 0.2 mm at the second molar balancing cusp inclines. The same author also suggested that a 15° alteration of the progressive side shift value (Transverse Horizontal Guidance) would result in a 0.8 mm error in the second molar cusp height on the working side.

The Cadiax® Compact system used for this study utilises an arbitrary hinge axis location. Many studies have examined the accuracy of an arbitrary or anatomical location of the hinge axis compared with using a kinematically located hinge axis. Schallhorn[103] is often cited as having demonstrated the relationship between kinematic and arbitrary location. Using an arbitrary location 13 mm along the tragus-outer canthus line 97% of kinematically determined axes were within a 5 mm radius of this point. Five millimetres had been considered to be the limit for clinically acceptable error. A recent study by Nagy[102] has confirmed these findings. Arbitrary and kinematically located axis points were compared. The results were favourable suggesting that the difference between arbitrary and kinematically located axis points for the 80 samples measured was 1.1 +/- 0.63 mm. 96.2% were within 2 mm and 67.5% were within 1 mm. The use of the arbitrary axis point with the Cadiax® Compact has been specifically tested. Bernhardt et al.[101] compared the arbitrary axis location with a kinematically located axis using the Cadiax® Compact. They observed that condylar inclination values determined kinematically and arbitrarily using the Cadiax® Compact demonstrated excellent reliability (ICC >0.8 with a SD of

< 5°). Repeated measurements for the sagittal condylar angulation using an arbitrary and kinematic hinge axis with the Gamma Cadiax and the Cadiax® Compact demonstrated excellent reliability. (SD approximately 5°).

6.12 Observations of Transverse Horizontal Guidance measurements between study groups.

The data for the Transverse Horizontal Guidance was collated for all groups. This data was not observed to be normally distributed. A clustering effect was noted with data points grouped at the minimum value (5°) and to a larger extent at the maximum value (15°).

Scatter plots were constructed and this trend was observed to occur between all study groups (Figure 5.3 and 5.4).

Quartile analysis was undertaken to describe the data distribution for the Transverse Horizontal Guidance values for different study groups. In addition to demonstrating this clustering effect about the minimum and maximum values a further observation could be made on the Transverse Horizontal Guidance values. The values for left and right sides differed slightly at the higher end of the spectrum with a slight tendancy for higher readings on the left side. The difference between the median and 75th percentile was 3 degrees (8-11°) for the right side and 6 degrees (8-14°) for the left side.

When the quartile analyses for Transverse Horizontal Guidance for all study groups were examined the median values were seen to be close to the overall median of 8°. The only exception to this was the increased vertical group who demonstrated a higher median value of 11°. This value is in agreement with that suggested for articulators with a fixed Transverse Horizontal Guidance of 7.5°[80]. It should be recognised that while the median values agreed with previous reports the clustering effect at 5° and 15° had not been reported previously and should be recognised as a possible limitation in the use of average value articulators.

6.13 Observations of Sagittal Condylar Inclination measurements between groups.

The results of Sagittal Condylar Inclination values for all of the study subgroups were subjected to quartile analysis. The measurements obtained for Sagittal Condylar Inclination were observed to be normally distributed. The data for right and left sides when analysed demonstrated the similar normal distributions and means and therefore were pooled for formal testing. While it is accepted that there may be some degree of dependence between values for the right and left sides it is also widely accepted that asymmetries do occur[62] and it would be considered normal for the two joints to give different values.

The means and standard deviations for the Sagittal Condylar Inclination of the different sagittal and vertical study groups are presented in tables 5.3-5.9.

The data for Sagittal Condylar Inclination was pooled for the right and left sides. Statistically significant differences were observed for the Sagittal Condylar Inclination values between the sagittal I and sagittal II subgroups ($p<0.05$) and between the sagittal II and the sagittal III subgroups ($p<0.001$).

Statistically significant differences were also observed for the Sagittal Condylar Inclination values when subjects were classified according to vertical skeletal pattern. Differences were observed between the reduced and average vertical groups ($p<0.05$) and between the average and increased vertical groups ($p<0.01$).

The results of this study suggest that the Sagittal Condylar Inclination values differ between subjects when grouped according to underlying skeletal pattern.

These differences may be relevant during prosthodontic management of patients with different skeletal patterns, particularly in the absence of suitable anterior guidance. The specific skeletal patterns which may be of concern include sagittal II, sagittal III and increased vertical relationships, particularly in the presence of an anterior open bite (negative vertical overlap). In such situations the development of an anterior guidance scheme may be particularly challenging due to the unfavourable horizontal and/or vertical overlap relationships between the anterior teeth. In such scenarios the posterior determinants of movement may be considered as having a more significant role.

The increased Sagittal Condylar Inclination observed in the sagittal II subgroup may be important during prosthodontic rehabilitation as frequently the development of anterior guidance may be challenging due to the increased horizontal overlap of the anterior teeth. In such circumstances an appropriately adjusted articulator may be indicated for establishing a dynamic occlusal relationship. Errors may be introduced during fabrication of restorations when the Sagittal Condylar Inclination in the articulator differs from that observed in the patient[1]. Furthermore using an articulator which more accurately reproduces the patient's movements allows the clinician to develop anterior guidance on suitably shaped restorations towards the anterior segment of the dentition.

The same argument can be made for the prosthodontic management of patients exhibiting sagittal III skeletal relationships or increased vertical skeletal patterns in the absence of adequate anterior guidance.

Previous studies have also observed differences in the Sagittal Condylar Inclination values when subjects with different orthodontic classifications were compared.

Zimmer et al.[19] demonstrated a statistically significant difference between the protrusive inclination (Sagittal Condylar Inclination) between sagittal I and sagittal III subjects with the sagittal III subjects exhibiting a flatter protrusive curve. This relationship was not observed in the present study as the sagittal I and sagittal III groups demonstrated similar Sagittal Condylar Inclination values. There was a tendency for shallower Sagittal Condylar Inclination values in the sagittal III subgroup compared with the sagittal I group but this did not approach statistical significance.

The results of the present study are in agreement with those of Zimmer et al. in relation to the Sagittal Condylar Inclination measurements of the sagittal II group compared with those of the sagittal III group. The Sagittal Condylar Inclination of our sagittal II group is significantly greater than that of the sagittal III group.

In the present study there was a statistically significant difference between the Sagittal Condylar Inclinations of the sagittal I and the sagittal II groups, with the sagittal II groups demonstrating a steeper Sagittal Condylar Inclination. No such difference was observed in the study conducted by Zimmer et al.

The trend for the Sagittal Condylar Inclination values in the present study agree with those of Zimmer et al. in that the sagittal III group demonstrate the shallowest Sagittal Condylar Inclination with the sagittal II group showing the steepest values for Sagittal Condylar Inclination. The differences in statistical observations may be explained to some extent by the similarity between the median values for protrusive curves in the Class I and Class II groups of the Zimmer et al. population.

The present study is in agreement with the results of two other studies [21, 22] who have demonstrated significantly steeper protrusive paths (Sagittal Condylar Inclination) in Class II division 2 subjects compared with Class I controls.

Stamm et al.[21] using the same instrumentation as in the present study demonstrated a significant difference between the condylar path inclination(Sagittal Condylar Inclination) in a Class II Division 2 population compared with a Class I control group. A limitation of this study was that they used dental relationships only so whilst the results agree the methods are not directly comparable.

Anders et al.[22] demonstrated a similar relationship between the Sagittal Condylar Inclination measurements of Class II division 2 subjects compared to Class I controls. This study population consisted of young adolescents suggesting that this relationship may continue throughout the growth period.

Little evidence is available in the literature regarding the effect of vertical skeletal pattern on mandibular movement. Some studies have attempted to assess the influence of an anterior open bite on mandibular movement [23, 24]. Differences in study methodology and classification of subjects do not allow for comparison with the observations made in the present study with respect to Sagittal Condylar Inclination measurements and vertical skeletal pattern.

Study	Main Findings
Zimmer et al.[19]	Grouped according to sagittal Skeletal Pattern. Similar trend with SCI greatest for Sagittal II and least for Sagittal III. Demonstrated a significant difference between Sagittal I & Sagittal III and between Sagittal II and Sagittal III.
Stamm et al.[21]	Grouped according to dental relationship. Class II division 2 significantly steeper SCI than Class I controls.
Anders et al.[22]	Grouped according to dental relationship. Class II division 2 steeper SCI than Class I controls.

Table 6-6 Previous studies demonstrating differences in Sagittal Condylar Inclination for subjects with various sagittal relationships.

6.14 Rejection of the null hypothesis.

The null hypothesis for this research project is that there is no difference in articulator settings between groups of patients demonstrating different skeletal patterns.

On the basis of the differences observed for Sagittal Condylar Inclination measurements for the sagittal and vertical study groups the null hypothesis can be rejected. There is a difference between the Sagittal Condylar Inclination of the sagittal I group and the sagittal II group, and between the sagittal II and the sagittal III group. On the basis of vertical skeletal pattern differences have been shown between the Sagittal Condylar Inclination measurements of the reduced vertical and the average vertical groups. Differences have also been observed between the average and increased vertical groups.

The degree of Transverse Horizontal Guidance, Immediate Side Shift and reference position reproducibility was also assessed with respect to the different study groups. The distribution of the data did not allow definitive conclusions to be made regarding differences arising from skeletal characteristics.

6.15 Recommendations.

The following recommendations can be made on the basis of the research undertaken:

1. In the prosthodontic management of Skeletal Class II patients consideration should be given to articulator settings. Values for Sagittal Condylar Inclination may be expected to be greater than would arise in a Class I or Class III patient.
2. In the prosthodontic management of patients exhibiting a vertical component to their malocclusion consideration should be given to articulator settings. Patients with a reduced vertical tendency or an increased vertical tendency may be expected to have greater Sagittal Condylar Inclination values than those with an average vertical pattern.
3. If extensive prosthodontic treatment is to be provided for a patient with a skeletal discrepancy, particularly in the absence of anterior guidance, adjustment to the Sagittal Condylar Inclination is advisable.
4. Mean values for Sagittal Condylar Inclination provided based on underlying skeletal pattern.* Where mean values are not to be used the clinician should consider the trend for sagittal condylar settings. (Reduced settings for Class III, increased settings for Class II and malocclusions with a vertical component).
5. Individual articulator settings may be deemed appropriate for extensive prosthodontic treatment in certain cases.

	Mean SCI setting *only appropriate for Denar Mark II
Sagittal I	45°
Sagittal II	49°
Sagittal III	42°
Reduced Vertical	48°
Average vertical	45°
Increased vertical	51°

Table 6-7 Recommended sagittal settings for Denar® Mark II based on underlying skeletal pattern.

6.16 Areas for future research.

Future areas of research in this field should include the evaluation of adult patients post-orthognathic surgery and adolescents treated with functional appliances to correct a skeletal discrepancy.

Assessment of the Sagittal Condylar Inclination in adults demonstrating a skeletal discrepancy measured before and after orthognathic surgery. This may indicate if clinically relevant remodelling within the TMJ may occur over time.

Similarly an observation of the Sagittal Condylar Inclination in adolescent orthodontic patients being treated with functional appliances may indicate the effect of growth modification upon condyle/fossa remodelling.

Other potential areas of interest for future research include:

- Examination of the influence of underlying skeletal pattern with regards to patients' age.
- Examination of the influence of tooth wear and the effect of a worn dentition on the resultant mandibular movement.

7. Conclusions

The results of this research project within the limitations of the study design suggest the following:

Assessment of underlying skeletal pattern from profile photographs appears to be reliable between prosthodontists and orthodontists. Agreement for sagittal classification of skeletal pattern is greater than for vertical classification.

Sagittal Condylar Inclination values vary according to the underlying skeletal pattern.

In the prosthodontic management of skeletal class II patients consideration should be given to articulator settings. Values for Sagittal Condylar Inclination may be expected to be greater than would arise in a class I or class III patient.

In the prosthodontic management of patients exhibiting a vertical component to their skeletal discrepancy consideration should be given to articulator settings. Patients with a reduced vertical tendency or an increased vertical tendency may be expected to have greater Sagittal Condylar Inclination values than those with an average vertical pattern.

No statistical differences were detected between study groups for Transverse Horizontal Guidance. However, interestingly, all study groups demonstrated clustering around the minimum (5°) and maximum (15°) values.

In general, the study population demonstrated a high degree of reproducibility for the reference position and for the majority Immediate Side Shift, of clinical relevance (>0.5 mm), was not present.

8. Appendix

8.1 Research proposal

Thesis Protocol.

Title.

Investigating the effect of skeletal pattern in determining articulator settings for prosthodontic rehabilitation: An In-vivo study.

Introduction.

Cephalometric studies have demonstrated differing condylar morphology and angulation between the three Angles classification groups[1,2,3]. Furthermore, anthropological and radiographic investigations have shown that the size and shape of the articular eminence of the TMJ is related to the underlying skeletal pattern[4,5,6,7].

Statement of problem and Literature Review.

According to the most recent NHANES-III survey in the United States it is estimated that at most only 30% of children and youths have a normal occlusion within the Angle's Class I category. The prevalence of Class II and Class III malocclusions in this population are estimated to be 15% and 1% respectively[8]. It should be noted however that there is considerable variation between prevalence figures and different geographic and ethnic samples[9]. For a Caucasian population the frequency of ClassII Division 1 is between 15%-20%, Class II Division 2 approximately 10% and Class III occurs in 3%[10].

In the course of extensive prosthodontic treatment an accurately set articulator is required. Having the posterior determinants approximate those observed in the individual maximises the opportunity to develop anatomically correct restorations and minimises the need for their occlusal adjustment at the fit appointment[11].

Frequently semi-adjustable or fully-adjustable articulators are used in the diagnostic and management phases of cases where considerable reconstruction is being provided. The operator has to make the decision whether to use average values and accept that these may vary from patient to patient. The alternative is to record excursive movements for the individual patient and programme the articulator accordingly. Methods used to achieve this include protrusive and lateral check bites, stereographic tracings and pantography.

The use of these additional procedures, although more time consuming, has been shown to more accurately reproduce the mandibular movement for individual patients[12].

Many manufacturers of dental articulators have average values indicated. How these values were arrived at should be known. It is also important to know how large a sample was used in obtaining these average values and whether this sample encompassed the various skeletal patterns encountered in everyday practice.

Before accepting average values thought should be given to the possible influence of the underlying skeletal pattern when undertaking prosthodontic treatment for such patients. If the condyle or articular eminence deviates from the norm, as has been demonstrated, this may influence mandibular movement and ultimately the morphology of the final restorations.

Numerous techniques have been used to assess the inclination of the articular eminence. Katsavrias[13] lists these as impressions, direct measurement, arthrograms, panoramic radiographs, tomographic radiographs (corrected and uncorrected), cephalometric radiographs, photographic measurement, cephalometry using intensifying screens, protrusive condylar path and wax. A shortcoming of cephalometric and other radiographic studies is that they frequently do not clearly demonstrate the TMJs[13] while those of an anthropological nature do not take into account the soft tissue contribution to the TMJ. The articular disc and the associated musculature have an integral role in mandibular movement[14]. For this reason axiography/pantography have been chosen for use in this study. These methods provide a non-invasive means of observing and recording the condylar inclination of individuals which can then be compared[15]. This data can then be utilised in the setting of articulators to replicate mandibular movement and facilitate the prosthodontic management of such patients.

The three systems listed (SAM - Axioquick®, Kavo - ARCUS-digma® and Waterpic Technologies - Cadiax®diagnostic with Gamma software) have featured previously in the literature and have been shown to be consistently accurate[16,17,18,19].

Aims of the study.

1. To record the average measurements for condylar inclination, laterotrusion, immediate mandibular lateral translation, and progressive mandibular lateral translation in a sample population consisting of Class I, Class II division1, Class II division2 and Class III subjects.
2. To investigate whether there are significant differences for the condylar inclination, laterotrusion, immediate mandibular lateral translation, and progressive mandibular lateral translation between these groups.
3. To make recommendations regarding "average values" for use in the prosthodontic management of these groups of patients.

Materials and Methods.

An ultrasonic axiograph (SAM - Axioquick®, Kavo - ARCUS-digma®) or electronic pantographic tracer (Waterpic Technologies - Cadiax®diagnostic with Gamma software) will be utilised for obtaining measurements for articulator settings.

Subjects.

Control group. Class I (Angle's classification and BSI classification)

Study groups. ClassII (Angle's Classification) Division 1 (BSI classification)

Class II (Angles classification) Division 2 (BSI classification)

Class III (Angle's classification)

Inclusion Criteria	***Exclusion criteria***
>16 years of age	Limitation of opening
Adult dentition	History of TMD
>12 opposing posterior teeth	Active orthodontic treatment
Within the limits of the Dublin Dental School and Hospital functional assessment criteria.	Previous orthodontic treatment
	Internal derangement (clicking within TMJ)

Study groups to be obtained from dental school students, staff and from orthodontic waiting lists and prosthodontic assessment clinics. Informed consent forms to be provided to each subject regarding the nature of the experiment.

Method for obtaining experimental data.

1. Obtain informed consent form from experimental subject.
2. Question patient regarding previous orthodontic treatment.
3. Functional assessment as per Dublin Dental School and Hospital protocol.
4. Assess ability of operator to locate centric relation with patient.

5. Mandibular movements to be rehearsed prior to recording until operator satisfied.
6. Patient to lightly occlude on Leaf gauge providing posterior disclusion while instrumentation being set up and attached.
7. Mandibular movements consisting of protrusion, lateral excursions and maximal opening to be executed and recorded.
8. Mandibular movements to be patient guided and operator assisted and originating from centric relation.

References.

1. Ari-Demirkaya A, Biren S, Ozkan H & Kucukkeles N. *Comparison of deep bite and open bite cases: normative data for condylar positions, paths and radiographic appearances.* **J Oral Rehab 2004;31:213-224**.
2. Burke G, Major P, Glover K, Prasad N. *Correlations between condylar characteristics and facial morphology in Class II preadolescent patients.* **Am J Orthod Dentofacial Orthop 2005;114(3):328-336.**
3. Baccetti T, Franchi L, McNamara JA Jr, Tollaro I. *Early dentofacial features of Class II malocclusion: a longitudinal study from the deciduous through the mixed dentition.* **Am J Orthod Dentofacial Orthop 1997;58(6):306-319.**
4. Ingervall B. *Relation between height of the articular tubercle and temporomandibular joint and facial morphology.* **Angle Orthodont 1974;44:15-24.**
5. Gianelly AA, Petras JC, Boffa J. *Condylar position and Class II deep-bite, no-overjet malocclusions.* **Am J Orthod Dentofacial Orthop 1989;96:428-432.**
6. Ricketts RM. *Variations of the temporomandibular joint as revealed by cephalometric laminography.* **Am J Orthod 1950;36:877-898.**
7. Katsavrias EG, Halazonetis DJ. *Condyle and fossa shape in Class II and Class III sheletal patterns: A morphometric tomographic study.* **Am J Orthod Dentofacial Orthop 2005;128(3):337-346.**
8. Proffit WR, Fields HW, Moray LJ. *Prevalencwe of malocclusion and orthodontic treatment need in the United States; estimates from the NHANES-III survey*. **Int J Adult Orthod Orthogn Surg 1998;13:97-106.**
9. El-Mangoury NH, Mostafa YA. *Epidemiologic panorama of dental occlusion.* **Angle Orthod. 1990;60(3):207-13.**
10. Mitchell L. *An Introduction to Orthodontics.* 2 Ed. 2001; Oxford Press.
11. Hobo S., Shillingburg HT, Whitsett LD. *Articulator selection for restorative dentistry.* **J Prosthet Dent 1976;36:35-43.**

12. Weinberg LA. *An evaluation of basic articulators and their concepts: Part III. Fully adjustable articulators.* **J Prosthet Dent 1963;13:873-888**.
13. Katsavrias EJ. *Changes in articular eminence inclination during the craniofacial growth period.* **Angle Orthodont 2002;72(3):258-264.**
14. Mc Devitt WE. *Functional Anatomy of the Masticatory System.* 1 Ed. 1989. Wright, London.
15. Zimmer B, Jager A, Kubein-Meesenburg D. *Comparison of "normal" TMJ function in ClassI, II and III individuals.* **Eur J Orthod 1991;13:27-34.**
16. Chang W, Romberg E, Drisoll CF, Tabacco MJ. *An in vitro evaluation of the reliability and validity of an electronic pantograpg by testing with five different articulators.* **J Prosthet Dent 2004;92(1):83-89**.
17. Bernhardt O, Kuppersa N, Rosin M, Meyer G. *Comparative test of arbitary and kinematic transverse horizontal recordings of mandibular movements.* **J Prosthet Dent 2003;89(2):175-179**
18. Baker PJ, Setchell DJ, Tredwin CJ. *Reproduction of articulator settings and movements with an ultrasonic jaw movement recorder.* **Eur J Prosthodont Restor Dent 2006;14(2)55-62.**
19. Kucukkeles N, Ozkan H, Ari-Demirkaya A, Cilingirturk AM. *Compatibility of mechanical and computerized axiographs: a pilot study.* **J Prosthet Dent 2005;94(2):190-4.**

8.2 Ethical Approval

8.2.1 University of Dublin Faculty of Health Sciences Research Ethics Committee.

THE UNIVERSITY OF DUBLIN

TRINITY COLLEGE

SCHOOL OF MEDICINE

FACULTY OF HEALTH SCIENCES

Trinity College, Dublin 2, Ireland
Tel: +353 1 896 1476
Fax: +353 1 671 3956
email: medicine@tcd.ie

Professor Dermot Kelleher, MD, FRCPI, FRCP, F Med Sci
Head of School of Medicine
Vice Provost for Medical Affairs

Ms Fedelma McNamara
School Administrator
email: fmcnamar@tcd.ie

Dr Thomas Canning
Post graduate Student, Dublin Dental Hospital

Wednesday, 20 December 2006

Study: Investigating the effect of skeletal pattern in determining articulaor settings for prosthodontic rehabilitation : an in vivo study

Dear Dr Canning

Further to a meeting of the Faculty of Health Sciences Research Ethics Committee in December 2006, we are pleased to inform you that the above project has been approved without further audit.

Yours sincerely

pp. Noelle Costelloe

Professor Chris Bell
Chairperson
Faculty of Health Sciences Research Ethics Committee

cc. Supervisor

Schools of the Faculty: Medicine, Dental Science, Nursing and Midwifery, Pharmacy and Pharmaceutical Sciences

8.2.2 Research Ethics Committee for the Adelaide & Meath Hospital, incorporating The National Children's Hospital.

Feidhmeannacht na Seirbhíse Sláinte
Health Service Executive

Local Health Manager (Louth)
PCCC Directorate, Dublin/North East
Oriel Suite
St. Brigid's Complex
Kells Road, Ardee, Co. Louth

Tel: +353 (0) 41 6860736
Fax: +353 (0) 41 6853766

AMH/DK/LHM

20th February 2008

Mr. Michael O'Sullivan
Senior Lecturer/Consultant in Restorative Dentistry (Special Needs)
Department of Restorative Dentistry & Periodontology
Dublin Dental School & Hospital,
Lincoln Place,
DUBLIN 2.

Dear Mr. O'Sullivan,

I refer to your letter of the 5th February 2008 regarding your project and request to include patients at Ashtown Gate.

I have discussed this matter with Dr. McSherry, Consultant Orthodontist and Muriel Farrell, Orthodontic Manager and are agreeable to your proceeding.

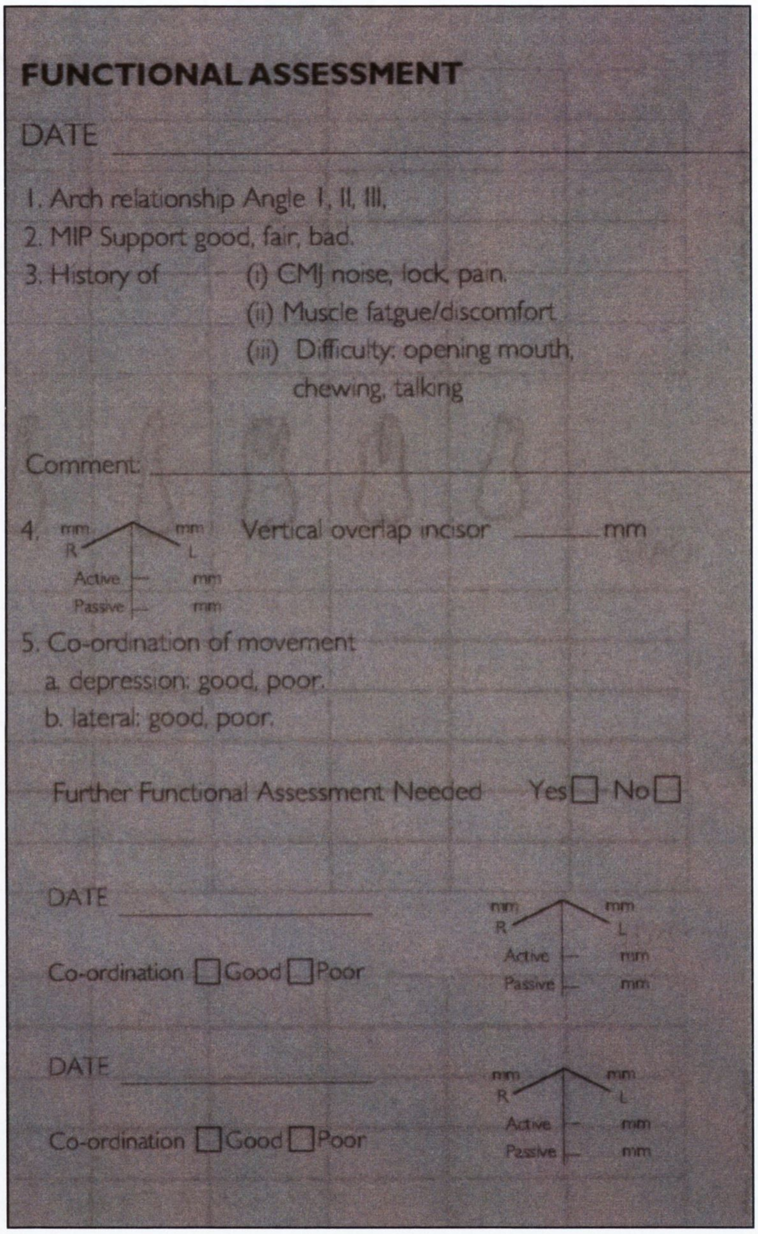
Yours sincerely,

Dymphna Keenan.

pp **Anne Marie Hoey,**
Local Health Manager – Louth
PCCC Directorate, HSE Dublin North East.

cc **Dr. Pat McSherry**
Muriel Farrell

8.3 Dublin Dental School Functional Assessment Criteria



FUNCTIONAL ASSESSMENT

DATE ____________

1. Arch relationship Angle I, II, III,
2. MIP Support good, fair, bad.
3. History of (i) CMJ noise, lock, pain.
(ii) Muscle fatgue/discomfort
(iii) Difficulty: opening mouth, chewing, talking

Comment: ____________

4. mm R mm L Active mm Passive mm Vertical overlap incisor ______ mm

5. Co-ordination of movement
a. depression: good, poor.
b. lateral: good, poor.

Further Functional Assessment Needed Yes☐ No☐

DATE ____________

Co-ordination ☐Good ☐Poor

mm R mm L Active mm Passive mm

DATE ____________

Co-ordination ☐Good ☐Poor

mm R mm L Active mm Passive mm

Figure 8-1 Dublin Dental School & Hospital functional assessment sheet.

8.4 Patient information sheet

PARTICIPANT INFORMATION

1. Title of study: Investigating the effect of skeletal pattern in determining articulator settings for prosthodontic rehabilitation: An In-vivo study.

2. Introduction: This study will require that subjects attend the Dublin Dental School and Hospital for a short (30 minutes approx) clinical appointment. A profile photograph will be taken of each participant. The participants will be shown the movements to be recorded and a period of time will be allocated to rehearse these. During this appointment a measuring device (Fig 1) will be temporarily attached to their upper and lower teeth. Sensors from this device will be connected to a laptop personal computer and recordings made digitally. The participant will be directed to make a series of movements of their lower jaw. To ensure participant's confidentiality is maintained they will each be assigned an individual number and all data recorded will be associated with this personal number. After the recordings have been made the measuring instrument will be removed from their teeth.

Fig 1.

3. Procedures: Participants will be selected for participation in the study on the basis of their underlying skeletal pattern. Participants must be over 18 years of age. Participants may be selected from within the Dental School and Hospital student body, staff members, patients attending assessment clinics and those currently receiving treatment at the Dental School and Hospital.
Participants will be asked to attend the clinic for one half hour appointment during which records will be made. A photograph of the patient in profile will be taken. An electronic measuring device will be attached temporarily to the participant's upper and lower teeth and a series of rehearsed jaw movements will be made.
Upon completion of this procedure the device will be removed from the teeth and the participant discharged.

4. Benefits: The individual's participation is the study will provide data which may be of benefit to the future restorative management of patients at the Dental School and Hospital and may contribute to the further education of undergraduate and postgraduate students.

5. Risks: The procedure is a simple measurement which carries no reported risks to the participant. The placement of the measuring device should not be associated with the participant experiencing any untoward incidents or discomfort.

6. Exclusion from participation: *You cannot participate in this study if any of the following are true*

- You experience limitation of mouth opening
- Have a history of TMD (Temporomandibular Dysfunction)
- Are undergoing active orthodontic treatment
- Have had previous orthodontic treatment

7. Confidentiality:
Your identity will remain confidential. Your name will not be published and will not be disclosed to anyone outside the study group. Each participant will be allocated a personal identification number which will be used to associate data recorded to the individual. Data will be retained at the Dublin Dental School and Hospital by the project supervisor in a secure area for a period of 5 years. This material will not be used in future unrelated studies without further specific permission being obtained.

8. Compensation:
This study is covered by standard institutional indemnity insurance. Nothing in this document restricts or curtails your rights.

9. Voluntary Participation: *You have volunteered to participate in this study. You may withdraw at any time. If you decide not to participate, or if you withdraw, you will not be penalised and will not give up any benefits that you had before entering the study.*

10. Stopping the study: *You understand that the investigators may withdraw your participation in the study at any time without your consent.*

11. Permission: This trial has Research Ethics Committee approval from all institutions involved.

12. Further information: *You can get more information or answers to your questions about the study, your participation in the study, and your rights, from Dr.Tom Canning .who can be telephoned at 01-6127383. If the study team learns of important new information that might affect your desire to remain in the study, you will be informed at once.*

Contact Details.

Dr. Tom Canning.
Dublin Dental School and Hospital
Hospital
Lincoln Place
Dublin 2.
Tel. 01-6127383
E Mail tom.canning@dental.tcd.ie

Dr. Michael O'Sullivan
Dublin Dental School and
Lincoln Place
Dublin 2.
Tel. 01-6127322

8.5 Informed consent sheet

Project: **Investigating the effect of skeletal pattern in determining articulator settings for prosthodontic rehabilitation: An In-vivo study.**

INFORMED CONSENT FORM

Principal Investigator: Dr. Tom Canning. Dublin Dental School and Hospital,
Lincoln place,
Dublin 2.
Tel. 01-6127383
Fax. 01-6127297
E Mail.
tom.canning@dental.tcd.ie
Supervisor: Dr. Michael O'Sullivan.
Dublin Dental School and
Hospital,
Lincoln place,
Dublin 2.
Tel. 01-6127322
Fax. 01- 6127297
E Mail. misullvn@dental.tcd.ie

BACKGROUND:

This study will require that subjects attend the Dublin Dental School and Hospital for a short (30 minutes approx) clinical appointment. A profile photograph will be taken of each participant. The participants will be shown the movements to be recorded and a period of time will be allocated to rehearse these. During this appointment a measuring device will be temporarily attached to their upper and lower teeth as per manufacturers' instructions using routine dental impression materials. Sensors from this device will be connected to a laptop personal computer and recordings made digitally. The participant will be directed to make a series of movements of their lower jaw. To ensure participant's confidentiality is maintained they will each be assigned an individual number and all data recorded will be associated with this personal number. After the recordings have been made the measuring instrument will be removed from their teeth.

DECLARATION:

I have read, or had read to me, this consent form. I have had the opportunity to ask questions and all my questions have been answered to my satisfaction.

I freely and voluntarily agree to be part of this research study, though without prejudice to my legal and ethical rights. I have received a copy of this agreement and I understand that, if there is a sponsoring company, a signed copy will be sent to that sponsor.

I understand I may withdraw from the study at any time.

(Name of sponsor:) ……………………………………………………………..

PARTICIPANT'S NAME:

……………………………………………………………..

CONTACT DETAILS:

……………………………………………………………..

PARTICIPANT'S SIGNATURE:

……………………………………………………………..

Date:…………………………….
Where the participant is incapable of comprehending the nature, significance and scope of the consent required, the form must be signed by a person competent to give consent to his or her participation in the research study (other than a person who applied to undertake or conduct the study). If the participant is a minor (under 18 years old) the signature of parent or guardian must be obtained: -

NAME OF CONSENTER, PARENT or GUARDIAN:…………………………………………………..

SIGNATURE:……………………………………………………………………
…………………………..

RELATION TO PARTICIPANT:…………………………………………………………………
………..

Statement of investigator's responsibility: I have explained the nature and purpose of this research study, the procedures to be undertaken and any risks that may be involved. I have offered to answer any questions and fully answered such questions. I believe that the participant understands my explanation and has freely given informed consent.

INVESTIGATOR'S SIGNATURE:………………………………………
Date:……………

8.6 British Standards Institute Incisor Classification

Classification	Description
Class I	The lower incisor edges occlude with or lie immediately below the cingulum plateau of the upper central incisors
Class II	The lower incisor edges lie posterior to the cingulum plateau of the upper incisors. Division 1: Upper central incisors are proclined or of average inclination and there is an increase in overjet Division 2: Upper central incisors are retroclined. The overjet is usually minimal but may be increased.
Class III	The lower incisor edges lie anterior to the cingulum plateau of the maxillary central incisors. The overjet is reduced or reversed.

Table 8-1 British Standards Institute Incisor Classification[31].

8.7 Angle's Classification

Classification	Description
Class I	The mesiobuccal cusp of the maxillary first molar occludes with the mesiobuccal grove of the mandibular first molar.
Class II	The mesiobuccal cusp of the mandibular first molar occludes distal to the class I position.
Class III	The mesiobuccal cusp of the mandibular first molar occludes mesial to the class I position

Table 8-2 Angle's Classification [29].

8.8 Clinical data recording sheet

Date_______________

Patient Code_________

Hx of previous ortho tx?

Functional Assessment:

Hx of Noise/Lock/Pain?

Co-Ordination of Movement:

Muscle fatigue/discomfort?

MIP Support:

Maximum opening	______mm
Left lateral	______mm
Right Lateral	______mm

Angle's Classification:	I	II	III
BSI Classification:	I	IIdiv1/2	III

8.9 Data recording sheet for skeletal classification

Thesis Data Sheet.

Please view PowerPoint presentation and place a tick in the accompanying box which you feel best describes the underlying skeletal pattern. Please place a tick under *both* the Horizontal and Vertical headings for each subject.

Subject Number	**Underlying Skeletal Pattern**					
	Horizontal			Vertical		
	Class I	Class II	ClassIII	Average vertical	Increased Vertical	Reduced Vertical
Subject Number 1						
Subject Number 2						
Subject Number 3						
Subject Number 4						
Subject Number 5						
Subject Number 6						
Subject Number 7						
Subject Number 8						
Subject Number 9						
Subject Number 10						
Subject Number 11						
Subject Number 12						
Subject Number 13						
Subject Number 14						
Subject Number 15						
Subject Number 16						
Subject						

Number 17						
Subject Number 18						
Subject Number 19						
Subject Number 20						
Subject Number 21						
Subject Number 22						
Subject Number 23						
Subject Number 24						
Subject Number 25						
Subject Number 26						
Subject Number 27						
Subject Number 28						
Subject Number 29						
Subject Number 30						
Subject Number 31						
Subject Number 32						
Subject Number 33						
Subject Number 34						
Subject Number 35						
Subject Number 36						
Subject Number 37						

Subject Number	**Underlying Skeletal Pattern**					
	Horizontal			Vertical		
	Class I	Class II	ClassIII	Average vertical	Increased Vertical	Reduced Vertical
Subject Number 38						
Subject Number 39						
Subject Number 40						
Subject Number 41						
Subject Number 42						
Subject Number 43						
Subject Number 44						
Subject Number 45						
Subject Number 46						
Subject Number 47						
Subject Number 48						
Subject Number 49						
Subject Number 50						
Subject Number 51						
Subject Number 52						
Subject Number 53						
Subject Number 54						
Subject Number 55						
Subject Number 56						
Subject Number 57						
Subject Number 58						

Subject Number 59						
Subject Number 60						
Subject Number 61						
Subject Number 62						
Subject Number 63						
Subject Number 64						
Subject Number 65						
Subject Number 66						
Subject Number 67						
Subject Number 68						
Subject Number 69						
Subject Number 70						
Subject Number 71						
Subject Number 72						
Subject Number 73						
Subject Number 74						

8.10 System for determining correlation between orthodontists and prosthodontists in allocating subjects according to sagittal and vertical skeletal pattern.

The scoring method was firstly to take the triple scores for sagittal classification for the prosthodontists and the orthodontists respectively. The orthodontist's scores were subtracted from the prosthodontist's scores and the *absolute* difference was determined. The sum of the absolute difference determined the degree of correlation between the assessors for the individual patients sagittal or vertical skeletal pattern.

	Sagittal I	Sagittal II	Sagittal III
Prosthodontists	0	2	1
Orthodontists	1	1	1
Absolute difference	1	1	0
Sum of Absolute difference = **2**			

Table 8-3 Method used to determine degree of correlation between orthodontists and prosthodontists in classifying participants according to sagittal and vertical skeletal pattern from profile photographs.

Using this method only four values are possible for the sum of the absolute difference. The only possible outcomes of this process are 0, 2, 4 and 6.

O= Total agreement between all assessors.

2= Good agreement between all assessors.

4= Poor agreement between all assessors.

6= Total disagreement between all assessors.

A statistical programme was written which generated random scores for the six groups (3x sagittal and 3x vertical) with a sample size of seventy-four. This process was repeated to obtain three thousand randomly selected data sets for seventy four subjects. The probability of obtaining an outcome on the basis of this simulation is listed below:

	Probability
0 (Total agreement)	0.1286
2 (Good agreement)	0.3456
4(Poor agreement)	0.3358
6 (Total disagreement)	0.19
	1

Table 8-4 Probability of obtaining a correlation value based on 3,000 repeated random samples of seventy four hypothetical subjects where each variable is measured six times.

Table 8.5 demonstrates the degree of agreement between the sagittal and vertical classification of subjects by the orthodontists and prosthodontists from facial profile photographs.

Score	Simulation	Saggital	Vertical
0 (Total agreement)	10	36	21
2 (Good agreement)	25	36	31
4(Poor agreement)	25	2	19
6 (Total disagreement)	14	0	3

Table 8-5 Correlation between orthodontists' and prosthodontists' classification of subjects according to sagittal and vertical skeletal pattern from profile photographs.*Simulation based on 3,000 random samples generated by computer programme.

8.11 Raw data for statistical analysis

Name	Hx Ortho Tx	Sagittal I	Sagittal II	Sagittal III	Reduced Vertical	Average Vertical	Increased Vertical
SJH 1	No			Sagittal III			Increased Vertical
SJH 2	No		Sagittal II		Reduced Vertical		
SJH 3	No			Sagittal III	Reduced Vertical		
SJH 4	No			Sagittal III		Average Vertical	
SJH 5	No			Sagittal III			Increased Vertical
SJH 6	No		Sagittal II				Increased Vertical
SJH 7	No			Sagittal III		Average Vertical	
SJH 8	No			Sagittal III		Average Vertical	
SJH 9	No		Sagittal II		Reduced Vertical		
SJH 10	No		Sagittal II			Average Vertical	
SJH 11	No		Sagittal II				Increased Vertical
SJH 12	No		Sagittal II				Increased Vertical
SJH 13	No		Sagittal II		Reduced Vertical		
SJH 14	No		Sagittal II			Average Vertical	
SJH 15	No			Sagittal III		Average Vertical	
SJH 16	No	Sagittal I					Increased Vertical
SJH 17	No		Sagittal II			Average Vertical	
SJH 18	No			Sagittal III		Average Vertical	
DDH 1	Yes		Sagittal II			Average Vertical	
DDH 2	Yes		Sagittal II			Average Vertical	
DDH 3	No		Sagittal II			Average Vertical	
DDH 4	No		Sagittal II		Reduced Vertical		
DDH 5	No	Sagittal I				Average Vertical	
DDH 6	No		Sagittal II			Average Vertical	
DDH 7	No		Sagittal II		Reduced Vertical		
DDH 8	No		Sagittal II		Reduced Vertical		
DDH 9	No		Sagittal II		Reduced Vertical		
DDH 10	Yes		Sagittal II			Average Vertical	
DDH 11	No	Sagittal I				Average Vertical	
DDH 12	No	Sagittal I				Average Vertical	
DDH 13	Yes		Sagittal II		Reduced Vertical		
DDH 14	Yes	Sagittal I				Average Vertical	
DDH 15	No	Sagittal I				Average Vertical	
DDH 16	Yes		Sagittal II			Average Vertical	
DDH 17	No		Sagittal II			Average Vertical	
DDH 18	Yes	Sagittal I				Average Vertical	
DDH 19	No	Sagittal I				Average Vertical	
DDH 20	Yes		Sagittal II		Reduced Vertical		
DDH 21	No	Sagittal I				Average Vertical	
DDH 22	No		Sagittal II		Reduced Vertical		
DDH 23	Yes		Sagittal II		Reduced Vertical		
DDH 24	No	Sagittal I				Average Vertical	
DDH 25	No		Sagittal II		Reduced Vertical		
DDh 26	Yes			Sagittal III		Average Vertical	
DDH 27	Yes		Sagittal II				Increased Vertical
DDH 28			Sagittal II		Reduced Vertical		
DDH 29				Sagittal III		Average Vertical	
DDH 30			Sagittal II		Reduced Vertical		

DDH 31		Sagittal I				Average Vertical	
DDH 32		Sagittal I				Average Vertical	
DDH 33			Sagittal II		Reduced Vertical		
DDH 34			Sagittal II		Reduced Vertical		
DDH 35			Sagittal II				Increased Vertical
DDH 36		Sagittal I				Average Vertical	
DDH 37				Sagittal III		Average Vertical	
DDH 38		Sagittal I				Average Vertical	
DDH 39			Sagittal II			Average Vertical	
DDH 40			Sagittal II		Reduced Vertical		
DDH 41			Sagittal II		Reduced Vertical		
DDH 42			Sagittal II		Reduced Vertical		
DDH 43				Sagittal III		Average Vertical	
DDH 44			Sagittal II			Average Vertical	
DDH 45							
DDH 46				Sagittal III	Reduced Vertical		
DDH 47			Sagittal II			Average Vertical	
DDH 48		Sagittal I				Average Vertical	
DDH 49			Sagittal II				Increased Vertical
DDH 50			Sagittal II		Reduced Vertical		
AG 1	No	Sagittal I				Average Vertical	
AG 2	No		Sagittal II			Average Vertical	
AG 3	No			Sagittal III		Average Vertical	
AG 4	No		Sagittal II				Increased Vertical
AG 5	No			Sagittal III		Average Vertical	
AG 6	No		Sagittal II				Increased Vertical
AG 7	No			Sagittal III		Average Vertical	

Name	**T.H.G. Right**	**T.H.G. left**	**S.C.I. Right**	**S.C.I. Left**	**ISS right**	**ISS left**
SJH 1	11	11	40	51	0	0.2
SJH 2	10	5	30	38	0	0
SJH 3	5	9	39	39	0	0.1
SJH 4	5	15	46	45	0	0
SJH 5	11	15	56	45	0	0
SJH 6	5	5	53	53	0	
SJH 7	7	5	38	39	0	0.2
SJH 8	8	5	38	35	0	0
SJH 9	13	15	57	45	0.2	0.3
SJH 10	7	14	47	45	0	0
SJH 11	15	15	65	44	0.4	0
SJH 12	13	15	52	48	0	0
SJH 13	12	10	48	58	0.1	0
SJH 14	10	15	48	62	0.2	0
SJH 15	9	15	44	42	0.1	0
SJH 16	15	15	52	60	0	0.6
SJH 17	5	7	46	40	0	0
SJH 18	14	15	47	38	0	0
DDH 1	9	7	45	45	0.1	0.1
DDH 2	9	11	41	46	0	0.1
DDH 3	5	5	43	42	0	0
DDH 4	5	5	52	60	0.1	0.1

DDH 5	11	8	42	45	0	0
DDH 6	5	5	50	50	1	0
DDH 7	5	5	53	56	0	0
DDH 8	15	9	55	53	0.3	0
DDH 9	14	9	49	37	0.3	0
DDH 10	10	7	49	48	0	0.2
DDH 11	5	7	60	57	0.2	0
DDH 12	6	15	48	55	0.2	0
DDH 13	5	5	47	55	0.2	0.1
DDH 14	10	15	45	59	0.1	0
DDH 15	8	5	51	49	0.1	0
DDH 16	8	7	60	52	0	0.1
DDH 17	12	13	52	52	0	0
DDH 18	6	6	40	38	0	0.1
DDH 19	5	5	31	35	0.3	0.4
DDH 20	8	6	60	59	0	0.1
DDH 21	5	5	48	44	0.5	0
DDH 22	5	6	51	51	0	0
DDH 23	15	5	56	41	0	0.2
DDH 24	8	5	39	39	0	0.3
DDH 25	14	9	50	39	0.4	0.1
DDh 26	5	13	36	45	0.2	0
DDH 27	5	7	54	51	0.2	0
DDH 28	15	15	60	60	0.5	0
DDH 29	11	7	51	52	0.1	0
DDH 30	5	11	50	52	0.1	0
DDH 31	5	8	35	29	0	0
DDH 32	5	15	37	40	0.1	0
DDH 33						
DDH 34	5	8	42	53	0	0
DDH 35	10	15	49	60	0	0
DDH 36	5	7	44	41	0	0
DDH 37	5	5	37	41	0	0.4
DDH 38	5	15	48	50	0.1	0
DDH 39	5	5	33	36	0.3	0
DDH 40	5	12	48	48	0	0.1
DDH 41	12	5	44	41	0	0
DDH 42	8	8	49	48	0	0
DDH 43	5	5	48	42	0	0
DDH 44	8	7	45	59	0.1	0
DDH 45	5	5	40	42	0	0.1
DDH 46	5	5	29	33	0.4	0
DDH 47	5	12	53	56	0.9	0.2
DDH 48	5	5	49	49	0.1	0
DDH 49	9	6	45	45	0.1	0
DDH 50	13	14	41	46	0	0
AG 1	11	15	37	52	0.2	0
AG 2	13	14	53	50	0	0
AG 3	11	14	46	44	0	0.1
AG 4	6	5	57	54	0.1	0

AG 5	8	11	38	44	0	0
AG 6	12	5	39	39	0.1	0
AG 7	8	11	41	45	0	0.2

Name	DX right	DZ right	DX left	DZ left	DY
SJH 1	0.09	0.18	0.02	0.08	0.12
SJH 2	0.12	0.15	0.41	0.58	0.06
SJH 3	0	0.07	0.23	0.04	0.08
SJH 4	0.24	0.1	0.02	0.23	0.25
SJH 5	0.18	0.13	0.16	0.11	0.17
SJH 6	0.72	0.73	0.58	1	0.26
SJH 7	0.19	0.05	0.34	0.39	0.05
SJH 8	1.79	1.2	0.59	0.36	0.41
SJH 9	0.09	0.32	0.1	0.04	0.24
SJH 10	0.8	0.96	0.7	0.72	0.19
SJH 11	0.09	0.16	0.01	0.24	0.17
SJH 12	0.01	0.05	0.07	0.22	0.11
SJH 13	0.2	0.44	0.31	0.6	0.05
SJH 14	0.32	0.18	0.65	0.24	0.26
SJH 15	0.03	0.2	1.36	0.81	0.5
SJH 16	0.02	0.13	0.03	0.25	0.16
SJH 17	0.09	0.1	0.02	0.03	0.51
SJH 18	0.01	0.04	0.45	0.5	0.21
DDH 1	0.23	0.07	0.34	0.14	0.05
DDH 2	0.13	0.12	0.36	0.36	0.27
DDH 3	0.04	0.06	0.36	0.09	0.05
DDH 4	0.08	0.06	0.1	0.04	0.11
DDH 5	0.22	0.32	0.24	0.05	0.04
DDH 6	0.05	0.05	0.12	0.15	0.14
DDH 7	0.14	0.14	0.16	0.14	0.15
DDH 8	0.2	0.13	0.2	0.42	0.38
DDH 9	0.11	0.06	0.48	0.83	0.15
DDH 10	0.16	0.1	0.03	0.03	0.05
DDH 11	0.02	0.02	0.07	0.31	0.09
DDH 12	0.03	0.19	0.06	0.18	0.09
DDH 13	0.47	0.31	0.31	0.46	0.05
DDH 14	0.08	0.26	0.38	0.21	0.04
DDH 15	1.24	1.71	0.74	0.8	0.12
DDH 16	0.02	0.12	0.12	0.03	0
DDH 17	0.3	0.46	0.44	0.74	0.16
DDH 18	0.15	0.12	0.1	0.22	0.17
DDH 19	0.28	0.13	0.19	0.08	0.02
DDH 20	0.02	0.46	0.08	0.08	0.08
DDH 21	0.03	0.01	0.17	0.01	0.41
DDH 22	0.22	0	0.12	0.01	0.06
DDH 23	0.11	0.38	0.3	0.46	0.03
DDH 24	0.17	0.12	0.71	0.48	0.14
DDH 25	0	0.07	0.07	0.25	0.07
DDh 26	0.14	0.19	0.05	0.05	0.23
DDH 27	0	0.4	0.07	0.02	0.03
DDH 28	0.12	0.35	0.03	0.06	0
DDH 29	0.41	0.54	0.45	0.69	0.22
DDH 30	0.01	0.33	0.09	0.16	0.39

DDH 31	0.05	0.17	0.8	0.56	0.08
DDH 32	0.02	0.02	0.16	0.13	0.1
DDH 33					
DDH 34	0.13	0.17	0.07	0.65	0.08
DDH 35	0.25	0.17	0.04	0.32	0.06
DDH 36	0.66	0.78	0.05	0.3	0.21
DDH 37	0.09	0.38	0.19	0.08	0.02
DDH 38	0.21	0.08	0.04	0.1	0.22
DDH 39	0.63	0.14	0.07	0.13	0.01
DDH 40	0.07	0.02	0.12	0.03	0.04
DDH 41	0.09	0.03	0.42	0.9	0.01
DDH 42	0.49	0.77	1.24	1.86	0.22
DDH 43	0.25	0.16	0.46	0.44	0.03
DDH 44	0.81	0.69	0.32	1.05	0.42
DDH 45	0.23	0.07	0.34	0.14	0.05
DDH 46	0.54	0.17	0.18	0.18	0.63
DDH 47	0.27	0.43	0.05	0.38	0.27
DDH 48	0.04	0.03	0.03	0.13	0.06
DDH 49	0.3	0.04	0.25	0.21	0.17
DDH 50	0.03	0.03	0.16	0.31	0.07
AG 1	0.34	0.29	0.17	0.26	0.26
AG 2	0.23	0.03	0.06	0.25	0.05
AG 3	0.16	0.31	0.19	0.3	0.3
AG 4	0.78	0.43	1.43	0.4	0.03
AG 5	1.23	0.89	0.63	0.64	0.28
AG 6	0.34	0.49	0.19	0.24	0.22
AG 7	0.2	0.12	0.32	0.34	0.19

References.

1. Hobo, S., H.T. Shillingburg, Jr., and L.D. Whitsett, *Articulator selection for restorative dentistry.* J Prosthet Dent, 1976. **36**(1): p. 35-43.
2. Celenza, F.V., *An analysis of articulators.* Dent Clin North Am, 1979. **23**(2): p. 305-26.
3. Starcke, E.N., *The history of articulators: from facebows to the gnathograph, a brief history of early devices developed for recording condylar movement: part II.* J Prosthodont, 2002. **11**(1): p. 53-62.
4. Lundeen, H.C. and C.H. Gibbs, *The function of teeth*. 1 ed. 2005: L and G Publishers. 92-93.
5. Payne, J.A., *Condylar determinants in a patient population: electronic pantograph assessment.* J Oral Rehabil, 1997. **24**(2): p. 157-63.
6. Rickets, R., *Laminography in the diagnosis of TMJ disorders.* The Journal of the American Dental Association, 1953. **46**: p. 620-648.
7. Ingervall, B., *Relation between height of the articular tubercle of the temporomandibular joint and facial morphology.* Angle Orthod, 1974. **44**(1): p. 15-24.
8. Pullinger, A.G., et al., *Relationship of mandibular condylar position to dental occlusion factors in an asymptomatic population.* Am J Orthod Dentofacial Orthop, 1987. **91**(3): p. 200-6.
9. Widman, D.J., *Functional and morphologic considerations of the articular eminence.* Angle Orthod, 1988. **58**(3): p. 221-36.
10. Gianelly, A.A., J.C. Petras, and J. Boffa, *Condylar position and Class II deep-bite, no-overjet malocclusions.* Am J Orthod Dentofacial Orthop, 1989. **96**(5): p. 428-32.
11. Seren, E., et al., *An evaluation of the condylar position of the temporomandibular joint by computerized tomography in Class III malocclusions: a preliminary study.* Am J Orthod Dentofacial Orthop, 1994. **105**(5): p. 483-8.
12. Cohlmia, J.T., et al., *Tomographic assessment of temporomandibular joints in patients with malocclusion.* Angle Orthod, 1996. **66**(1): p. 27-35.
13. Ikai, A., et al., *Morphologic study of the mandibular fossa and the eminence of the temporomandibular joint in relation to the facial structures.* Am J Orthod Dentofacial Orthop, 1997. **112**(6): p. 634-8.
14. Burke, G., et al., *Correlations between condylar characteristics and facial morphology in Class II*

preadolescent patients. Am J Orthod Dentofacial Orthop, 1998. **114**(3): p. 328-36.
15. Akahane, Y., T. Deguchi, and N.P. Hunt, *Morphology of the temporomandibular joint in skeletal class iii symmetrical and asymmetrical cases: a study by cephalometric laminography.* J Orthod, 2001. **28**(2): p. 119-28.
16. Kikuchi, K., et al., *Association between condylar position, joint morphology and craniofacial morphology in orthodontic patients without temporomandibular joint disorders.* J Oral Rehabil, 2003. **30**(11): p. 1070-5.
17. Katsavrias, E.G. and D.J. Halazonetis, *Condyle and fossa shape in Class II and Class III skeletal patterns: a morphometric tomographic study.* Am J Orthod Dentofacial Orthop, 2005. **128**(3): p. 337-46.
18. Katsavrias, E.G., *Morphology of the temporomandibular joint in subjects with Class II Division 2 malocclusions.* Am J Orthod Dentofacial Orthop, 2006. **129**(4): p. 470-8.
19. Zimmer, B., A. Jager, and D. Kubein-Meesenburg, *Comparison of 'normal' TMJ-function in Class I, II, and III individuals.* Eur J Orthod, 1991. **13**(1): p. 27-34.
20. Ogawa, T., K. Koyano, and T. Suetsugu, *Characteristics of masticatory movement in relation to inclination of occlusal plane.* J Oral Rehabil, 1997. **24**(9): p. 652-7.
21. Stamm, T., et al., *Computer-aided axiography of asymptomatic individuals with Class II/2.* J Orofac Orthop, 1998. **59**(4): p. 237-45.
22. Anders, C., W. Harzer, and L. Eckardt, *Axiographic evaluation of mandibular mobility in children with angle Class-II/2 malocclusion (deep overbite).* J Orofac Orthop, 2000. **61**(1): p. 45-53.
23. Ari-Demirkaya, A., et al., *Comparison of deep bite and open bite cases: normative data for condylar positions, paths and radiographic appearances.* J Oral Rehabil, 2004. **31**(3): p. 213-24.
24. Koak, J.Y., K.N. Kim, and S.J. Heo, *A study on the mandibular movement of anterior openbite patients.* J Oral Rehabil, 2000. **27**(9): p. 817-22.
25. Mc Devitt, W.E., *The craniomandibular joint*, in *Functional anatomy of the masticatory system*. 1989. p. 69-96.
26. *Anatomy of facial and oral structures*. [cited; Available from: www.homesteadschools.com.
27. Wilkinson, T.M., *The relationship between the disk and the lateral pterygoid muscle in the human temporomandibular joint.* J Prosthet Dent, 1988. **60**(6): p. 715-24.
28. Mitchell, L., *An introduction to orthodontics*. 1 ed. 1996: Oxford University Press. 10.
29. Angle, E.H., *Classification of malocclusion.* Dental Cosmos, 1899. **41**: p. 248-264.
30. Mitchell, L., *An introduction to orthodontics*. 1 ed. 1996: Oxford University Press. 11.

31. *British Standard Incisor Classification*, in *Glossary of Dental Terms BS 4492.* 1983, British Standard Institute: London.
32. Mitchell, L., *An introduction to orthodontics*. 1 ed. 1996: Oxford University Press. 44-47.
33. Riedel, R.A., *The relation of maxillary structures to cranium in normal occlusion.* Angle Orthod, 1952. **22**: p. 142-145.
34. Jacobson, A., *The "Wits" appraisal of jaw disharmony.* Am J Orthod, 1975. **67**(2): p. 125-38.
35. Mitchell, L., *An introduction to orthodontics*. 1 ed. 1996: Oxford University Press. 45.
36. Proffit, W.R., H.W. Fields, and D. Sarver, *Contemporary Orthodontics*. 4 ed. 2006: Elsevier/Mosby. 5.
37. Farkas, L.G., et al., *Comparison of anthropometric and cephalometric measurements of the adult face.* J Craniofac Surg, 1999. **10**(1): p. 18-25; discussion 26.
38. Mitchell, L., *An introduction to orthodontics*. 1 ed. 1996: Oxford University Press. 92.
39. Mitchell, L., *An introduction to orthodontics*. 1 ed. 1996: Oxford University Press. 104.
40. Mitchell, L., *An introduction to orthodontics*. 1 ed. 1996: Oxford University Press. 114.
41. Proffit, W.R., H.W. Fields, Jr., and L.J. Moray, *Prevalence of malocclusion and orthodontic treatment need in the United States: estimates from the NHANES III survey.* Int J Adult Orthodon Orthognath Surg, 1998. **13**(2): p. 97-106.
42. El-Mangoury, N.H. and Y.A. Mostafa, *Epidemiologic panorama of dental occlusion.* Angle Orthod, 1990. **60**(3): p. 207-14.
43. Katsavrias, E.G., *Changes in articular eminence inclination during the craniofacial growth period.* Angle Orthod, 2002. **72**(3): p. 258-64.
44. Corbett, N.E., et al., *The relation of the condylar path to the articular eminence in mandibular protrusion.* Angle Orthod, 1971. **41**(4): p. 286-92.
45. Hellsing, G., *Human jaw muscle motor behaviour. I. Motor drive.* Swed Dent J, 1987. **11**(6): p. 251-61.
46. Shillingburg, H., *Fundamentals of fixed prosthodontics*. 3 ed. 1997: Quintessence Books. 13-14.
47. Christensen, C., *The problem of the bite.* Dental Cosmos, 1905. **18**: p. 1184-1195.
48. Luce, C., *The movements of the lower jaw.* Boston Med Surg J, 1889(121): p. 8-11.
49. Starcke, E.N., *The history of articulators: early attempts to reproduce mandibular movement, Part III: searching for the solution to a puzzle.* J Prosthodont, 2000. **9**(4): p. 217-22.
50. D'Amico, A., *Functional occlusion in the natural teeth in man.* J Prosthet Dent, 1961(11): p. 899-915.
51. Shaw, D., *Form and function in teeth and a rational unifying principle applied to interpretation.* Int J Orthodont, 1924. **10**: p. 703-718.

52. Stuart, C. and H. Stallard, *Concepts of occlusion.* Dental Clin North Am, 1963(7): p. 591.
53. Shillingburg, H., *Fundamentals of fixed prosthodontics*. 3 ed. 1997: Quintessence Books. 19-20.
54. Becker, C.M. and D.A. Kaiser, *Evolution of occlusion and occlusal instruments.* J Prosthodont, 1993. **2**(1): p. 33-43.
55. Hockel, J., *Organic occlusion, the goal of gnathology*, in *Orthopaedic Gnathology*, J. Hockel, Editor. 1983: Chicago. p. 19-43.
56. McHorris, W.H., *The improtance of anterior teeth.* The Journal of Gnathology, 1982. **1**(1): p. 19-36.
57. Shillingburg, H., *Fundamentals of fixed prosthodontics*. 3 ed. 1997: Quintessence Books. 22.
58. Schuyler, C.H., *The function and importance of incisal guidance in oral rehabilitation.* J Prosthet Dent, 1963. **13**(6): p. 1011-1029.
59. Lee, R., *Esthetics and its relation to function*, in *Fundamentals of esthetics*, C. Rufenacht, Editor. 1990, Quintessence Publishing: Chicago. p. 137-209.
60. Jankelson, B., *Dental Occlusion and the Temporomandibular Joint.* Dental Clin North Am, 1962: p. 51-62.
61. Ramjford, J. and M. Ash, *Occlusion*. 1966, Philadelphia: W.B. Saunders Co. 66, 84, 161, 193.
62. Bell, D.E. and E.F. Harris, *Disclusion in mandibular protrusion.* Angle Orthod, 1983. **53**(2): p. 146-56.
63. Mongini, F., *Relationship between the temporomandibular joint and pantographic tracings of mandibular movements.* J Prosthet Dent, 1980. **43**(3): p. 331-7.
64. *The glossary of prosthodontic terms.* J Prosthet Dent, 2005. **94**(1): p. 10-92.
65. Lee, R.L., *Jaw movements engraved in solid plastic for articulator controls. II. Transfer apparatus.* J Prosthet Dent, 1969. **22**(5): p. 513-27.
66. Lee, R.L., *Jaw movements engraved in solid plastic for articular controls. I. Recording apparatus.* J Prosthet Dent, 1969. **22**(2): p. 209-24.
67. Lundeen, H.C. and C.G. Wirth, *Condylar movement patterns engraved in plastic blocks.* J Prosthet Dent, 1973. **30**(6): p. 866-75.
68. Stuart, C., *Good occlusion for natural teeth.* J Prosthet Dent, 1964. **14**(4): p. 716-724.
69. Ramjford, J. and M. Ash, *Occlusion*. 2 ed. 1971, Philadelphia: W.B. Saunders Co. 118.
70. Ramjford J, *Dysfunctional temporomandibular joint and muscle pain.* J Prosthet Dent, 1961. **11**: p. 353-374.
71. Stallard, H. and C. Stuart, *Eliminating tooth guidance in natural dentitions.* J Prosthet Dent, 1961(11): p. 474-479.
72. Schuyler, D., *Factors contributing to traumatic occlusion.* J Prosthet Dent, 1961(11): p. 708-715.

73. Whitsett, L.D., H.T. Shillingburg, Jr., and M.G. Duncanson, *The nonworking interference.* J Okla Dent Assoc, 1974. **65**: p. 5-8.
74. Guichet, N., *Occlusion*. 1970, Anaheim: Denar Corporation. 66.
75. Stuart, C., *Why dental restorations should have cusps.* J South Calif Dent Assoc, 1959. **27**: p. 198-200.
76. Wachtel, H.C. and D.A. Curtis, *Limitations of semiadjustable articulators. Part I: Straight line articulators without setting for immediate side shift.* J Prosthet Dent, 1987. **58**(4): p. 438-42.
77. Curtis, D.A. and H.C. Wachtel, *Limitations of semiadjustable articulators. Part II: Straight line articulators with provision for immediate side shift.* J Prosthet Dent, 1987. **58**(5): p. 569-73.
78. Posselt, U., *Movement areas of the mandible.* J Prosthet Dent, 1957. **7**: p. 375.
79. Wilson, P.H. and A. Banerjee, *Recording the retruded contact position: a review of clinical techniques.* Br Dent J, 2004. **196**(7): p. 395-402; quiz 426.
80. Lundeen, H.C. and C.H. Gibbs, *The function of teeth*. 1 ed. 2005: L and G Publishers.
81. Gibbs, C.H., et al., *Chewing movements in relation to border movements at the first molar.* J Prosthet Dent, 1981. **46**(3): p. 308-22.
82. Woda, A., P. Vigneron, and D. Kay, *Nonfunctional and functional occlusal contacts: a review of the literature.* J Prosthet Dent, 1979. **42**(3): p. 335-41.
83. Gross, M.D. and C.E. Nemcovsky, *Investigation of the effects of a variable lateral guidance incline on the pantronic registration of mandibular border movement: Part II.* J Prosthet Dent, 1993. **70**(4): p. 336-44.
84. Otake, T., et al., *The role of posterior guidances under the altered anterior guidance.* J Oral Rehabil, 2002. **29**(12): p. 1196-205.
85. GAMMAGmbH, *Cadiax® Compact TMJ movement recording*. Vol. 1. 2005.
86. Panadent. *7600 AP Axi-Path III Recorder*. [cited; Available from: http://www.panadent.com/html/axi-path_recorders.html.
87. Posselt, U. and G. Franzen, *Registration of the condylar path inclination by intraoral wax records: variations in three instruments.* J Prosthet Dent, 1960(10): p. 441-454.
88. Gross, M., et al., *The effect of three different recording materials on the reproducibility of condylar guidance registrations in three semi-adjustable articulators.* J Oral Rehabil, 1998. **25**(3): p. 204-8.
89. Ecker, G.A., C.J. Goodacre, and R.W. Dykema, *A comparison of condylar control settings obtained from wax interocclusal records and simplified mandibular motion analyzers.* J Prosthet Dent, 1984. **51**(3): p. 404-6.

90. Johnson, A. and R.B. Winstanley, *Recording sagittal condylar angles using a mandibular facebow.* J Oral Rehabil, 1997. **24**(12): p. 904-8.
91. dos Santos, J., Jr., S. Nelson, and T. Nowlin, *Comparison of condylar guidance setting obtained from a wax record versus an extraoral tracing: a pilot study.* J Prosthet Dent, 2003. **89**(1): p. 54-9.
92. Wise, M.D., *Occlusion and restorative dentistry for the general practitioner. Part 5-Principles and types of articulators and techniques for recording jaw positions-'jaw registration.* Br Dent J, 1982. **152**(8): p. 277-87.
93. Winstanley, R.B., *Observations on the use of the Denar pantograph and articulator.* J Prosthet Dent, 1977. **38**(6): p. 660-72.
94. Beard, C.C., K. Donaldson, and J.A. Clayton, *Comparison of an electronic and a mechanical pantograph. Part I: Consistency of an electronic computerized pantograph to record articulator settings.* J Prosthet Dent, 1986. **55**(5): p. 570-4.
95. Price, R.B. and R.A. Bannerman, *A comparison of articulator settings obtained by using an electronic pantograph and lateral interocclusal recordings.* J Prosthet Dent, 1988. **60**(2): p. 159-64.
96. Ratzmann, A., et al., *Comparative clinical investigation of horizontal condylar inclination using the JMA electronic recording system and a protrusive wax record for setting articulators.* Int J Comput Dent, 2007. **10**(3): p. 265-84.
97. Pelletier, L.B. and S.D. Campbell, *Comparison of condylar control settings using three methods: a bench study.* J Prosthet Dent, 1991. **66**(2): p. 193-200.
98. Celar, A.G. and K. Tamaki, *Accuracy of recording horizontal condylar inclination and Bennett angle with the Cadiax compact.* J Oral Rehabil, 2002. **29**(11): p. 1076-81.
99. Chang, W.S., et al., *An in vitro evaluation of the reliability and validity of an electronic pantograph by testing with five different articulators.* J Prosthet Dent, 2004. **92**(1): p. 83-9.
100. Petrie, C.S., G.D. Woolsey, and K. Williams, *Comparison of recordings obtained with computerized axiography and mechanical pantography at 2 time intervals.* J Prosthodont, 2003. **12**(2): p. 102-10.
101. Bernhardt, O., et al., *Comparative tests of arbitrary and kinematic transverse horizontal axis recordings of mandibular movements.* J Prosthet Dent, 2003. **89**(2): p. 175-9.
102. Nagy, W.W., T.J. Smithy, and C.G. Wirth, *Accuracy of a predetermined transverse horizontal mandibular axis point.* J Prosthet Dent, 2002. **87**(4): p. 387-94.
103. Schallhorn, R.G., *A study of the arbitrary centre and the kinematic centre of rotation for facebow mountings.* J Prosthet Dent, 1957. **7**: p. 162-169.

104. Weinberg, L., *An evaluation of basic articulators and their concepts. Part II. Arbitrary, positional and semi-adjustable articulators.* J Prosthet Dent, 1961. **13**(4): p. 645-663.
105. Slaviceck, C. 2007.
106. Kuyl, M.H., R.M. Verbeeck, and L.R. Dermaut, *The integumental profile: a reflection of the underlying skeletal configuration?* Am J Orthod Dentofacial Orthop, 1994. **106**(6): p. 597-604.
107. L'Estrange, P.R. and C.G. Murray, *Application of lateral skull cephalometry to prosthodontics.* Aust Orthod J, 1976. **4**(4): p. 146-52.
108. Mc Collum, B.B. and C.E. Stuart, *A research report.* South Pasedena, Calif: Scientific Press, 1955.
109. Lundeen, H.C., E.F. Shryock, and C.H. Gibbs, *An evaluation of mandibular border movements: their character and significance.* J Prosthet Dent, 1978. **40**(4): p. 442-52.
110. Craddock, F.W., *The accuracy and practical value of records of condyle path inclination.* Journal of the American Dental Association, 1949. **38**: p. 697-710.