Effect of Different Mounting Methods on Programming the Dental Articulator

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ABSTRACT

**Statement of the problem.** The effect of different mounting methods on programming the dental articulator continues to be a controversial procedure especially when new devices are being marketed.

**Specific aims.** The purpose of this clinical and laboratory study was to evaluate the effect of different mounting methods on programming the dental articulator.

**Materials and methods.** 10 healthy volunteer dental students were selected for this study. Clinical records including: maxillary and mandibular impressions, face/earbow records using 4 different systems, 5 inter-occlusal records (CR, MIP, right and left lateral excursive, and protrusive) were made for each patient, as well as electronic pantographic tracing (Cadiax). Clinical records were used in vitro to mount casts to 5 different articulator systems and to program the articulator HCI and Bennett angle. Values obtained both digitally from the Cadiax compact 2 system and from the analog inter-occlusal records were compared amongst the different systems. Repeated angular measurements by the two trained investigators were first analyzed for reliability between observers, using the single score technique of Shrout and Fleiss. The data was statistically analyzed using 3-way repeated-measures ANOVA, and Student’s t-tests with Bonferroni corrections were used for pairwise comparisons.

**Results.** The intra-class correlation was found to be excellent (0.99). The null hypothesis
was rejected due to statistical significant difference found with Hanau system in both protrusive condylar inclination as well as lateral Bennett angle when compared to other systems studied. Deanr Mark 330 and Whip Mix 2340 showed statistical difference in lateral angles when compared to the Cadiax Comapct 2 and their system specific digital values generated by the Cadiax Compact 2 electronic pantograph. Also, Max Align was found to be statistically different to both Whip Mix articulators (2240 and 2340) when comparing protrusive condylar inclination.

**Conclusion.** Differences in HCI and Bennett angle can be anticipated when using the Hanau ‘Wide Vue’ articulator. Newly introduced Max Align mounting system proved comparable to other articulator systems on the market.
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<td>CI</td>
<td>Confidence Interval</td>
</tr>
<tr>
<td>CR</td>
<td>Centric Relation</td>
</tr>
<tr>
<td>IMLT</td>
<td>Immediate Mandibular Lateral Translation</td>
</tr>
<tr>
<td>MIP</td>
<td>Maximum intercuspation position</td>
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<td>LCI</td>
<td>Lateral Condylar Inclination</td>
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<td>PMLT</td>
<td>Progressive Mandibular Lateral Translation</td>
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<td>THA</td>
<td>Transverse Horizontal Axis or Terminal Hinge Axis</td>
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<tr>
<td>TMJ</td>
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CHAPTER 1

INTRODUCTION

Dental prostheses are often fabricated indirectly on a semi adjustable articulator due to their ease in programming compared to complex fully adjustable articulators. Correct programing of the articulator to simulate the patient is essential in extensive and complex cases of oral rehabilitation, in order to fabricate optimum prostheses that accomplish the functional and esthetic necessities of these patients.

The goal of registering mandibular movements remains essential to recreate the patient’s dynamic occlusion and movement patterns as closely as possible on the dental articulator (Anthony, 1942). Pantographic tracings have been traditionally used to record the various condylar movements, in order to customize the fully adjustable articulator for a given patient. The ultimate goal has been to record each specific condylar position in every plane of movement. It has been particularly recommended to utilize the pantographic tracings to record border movements in programming the articulator for complex prosthetic rehabilitation situations (Clayton et al, 1971; and Lundeen et al, 1978). Several studies have been conducted to evaluate the validity and reliability of the more contemporary electronic pantograph, which was found to be reliable and valid (Curtis and Sorensen, 1986; Price and Bannerman, 1988; Celar and Tamaki, 2002;
and Chang et al, 2004).

Prior to fabricating any prostheses, the dental casts are to be positioned on the articulator in the three dimensions of space, namely, frontal, sagittal and horizontal planes. This requires recording the correct special orientation, namely, vertical and horizontal relations (Bauer and Gutowski, 1976; and Berman 1960). The maxillary cast is mounted on the articulator using three points of reference, two posterior and one anterior to the maxilla. These points determine the plane of orientation that is the baseline from which all occlusal relationships start. A variation in the supero-inferior position of the casts can alter the protrusive condylar guidance on the articulator, rendering the reliability of these anterior reference points in orienting the maxillary cast on the articulator questionable (Bailey and Nowlin, 1984).

Clinical and laboratory studies have shown significant controversy regarding the reliability of the digital pantograph to accurately record mandibular movements (Palik et al, 1985; Chang et al, 2004; and Taylor et al, 2016). A limited number of publications exist that have tested the accuracy of commercially available computerized pantographs in vivo, which have reported conflicting data in tracking mandibular condylar movements and to program dental articulator (Taylor et al, 2016).

Additionally, a recently introduced digital device (Max Align, Whip Mix Corp.) has been claimed to replace the traditional Face/earbow and also be used to mount maxillary casts onto the articulator.

It has been reported that a great majority of restorative cases are being sent to the lab without any type of patient photography, and also occasionally inter-occlusal records
and facebow registration records are missing as well. This information is critical for the lab technician to mount casts on an articulator to be able to produce accurate prosthesis (Zarb and Bolender, 2004). Recently, Whip Mix Corp. introduced a digital device (Max Align, Whip Mix Corp.) that has been claimed to replace the traditional Face/earbow and also be used to mount maxillary casts onto the articulator. This device uses photography taken on a tablet to capture vital patient landmarks that show the relationship between the upper teeth and the patient’s head. Also, it will capture the patient’s facial midline, horizontal cant and anterior/posterior angle. The saved photo with landmarks can then be sent to the laboratory for mounting models on most Denar, Hanau and Whip Mix articulators. According to the manufacturer, this device can be used for many cases, such as esthetic, edentulous and three-plus unit restorations. Max Align is introduced to act as a communication tool for both the dentist and the lab to share the needs of the patient, document the patient’s case, and to produce accurate prosthesis.

Within the classification of the articulator there are different brands that utilize different reference point to assist in mounting the casts. For example, Whip Mix utilize the nasion as the third point of reference, Denar uses the premeasured 43 mm from the incisal edge of the maxillary lateral incisor and lateral side of the nose, and Hanau utilize the infra-orbital notch. On the other hand, the digital Max Align device utilizes two reference lines (the vertical midline and the horizontal inter-pupillary line) to transfer the orientation of the maxilla to the articulator. Whether those different mounting methods lead to similar orientation and articulator settings has not been investigated.
CHAPTER 2

REVIEW OF LITERATURE

Historical Background

The term “Gnathology” has been used to define the science of the anatomy, histology, physiology and pathology of the stomatognathic system, whereby treatment of the ailing dentition, is based on examination, diagnosis and careful planning. Stallard in 1924 described this approach of comprehensive dentistry (Stuart and Golden 1981 and Pokorny et al 2008). The stomatognathic system includes teeth, supporting tissues, temporomandibular joints (TMJ) and all associated hard and soft tissues of the head and neck (Bauer and Gutowski, 1976; Starke, 2002; GPT-9, 2017; and Pokorny et al, 2008). Gnathology is based on the following fundamentals of occlusion: centric relation, anterior guidance, occlusal vertical dimension, the intercuspal schemes, as well as the relationship between the determinants of mandibular movements utilizing mandibular recording instruments (Stuart and Golden, 1981 and Pokorny et al, 2008).

The Human Masticatory system

The integrity and equilibrium of the entire human masticatory system is dependent on balance between the elevator and depressor muscles controlling mandibular
movements (Dawson, 2008 and Mack, 1991). Goldspink (1976) pointed out that accurate determinant for the relation between the mandible to the maxilla was in fact the act of repetitive contracted length of the elevator muscles. This process is expressed during eruption of teeth, as teeth oppose each other until there is balance between the eruptive forces. At which stage, the mandible assumes a position vertical to the maxilla influenced by the repetitive power cycles of the closing elevator muscles. The teeth hence adapt to the vertically positioned mandible and assume their role as anterior determinants for mandibular movements (Goldspink, 1976).

Physiologic vs. Pathologic Occlusion

The harmonious relationship between the anatomic determinants of mandibular movements and the neuromuscular control response, have been referred to as “physiologic occlusion” (Thompson, 1946; Dhal and Krogstad, 1985; Trapozzano and Lazzari, 1961; and Van Sickels et al, 1985). This meant that occlusal inclines of teeth should be in harmony with each other as well as in harmony with other anatomic controls of mandibular movements, such as TMJs. In contrast, insufficient harmony existed when the occlusal conditions induced stresses beyond the physiologic limit of the tissues. In such situations, pathologic symptoms, such as muscle pain and headache, would develop. Hellsing (1984) demonstrated that jaw muscle tonicity adapted to extreme changes in vertical dimension, and that tooth contacts were critical in influencing periodontal receptor afferent discharge, which is responsible for the adaptation feedback mechanism.
The Transverse Horizontal Axis and the Face/Earbow transfer

The transverse horizontal axis (THA) is defined as an imaginary line around which the mandible may rotate within the sagittal plane (GPT-9, 2017). The kinematic (true) hinge axis is usually determined by the pantograph, whereas the arbitrary axis is determined by the either the facebow or earbow (Walker, 1980). These are used to identify the THA and relate the occlusal surfaces of the maxillary teeth to this axis. The arbitrary earbow differs from the kinematic facebow in that it utilizes anatomic averages to locate the transverse horizontal axis; whereas, the kinematic determines the exact location of the axis of rotation of the mandible. The arbitrary earbow relates the maxillary teeth to the transverse horizontal axis by utilizing the right and left external auditory meatus, whereas the traditional facebow rests on the face anterior to the ear at an estimated location 13 mm anterior to the tragus of the ear on a line from the tragus to the outer canthus of the eye (Schallhorn, 1957; Weinberg, 1961; and Preston, 1979).

Teteruck and Lundeen (1966) compared mounting maxillary casts using the facebow and 13 mm tragus-canthus point to the kinematic hinge axis. It was found that 33% of the arbitrary axis points fell within 6 mm radius of the kinematic axis. However, this percentage increased to 56.4% when using the earbow. Interestingly, with a simple modification of the ear plug, the percentage increased to 75.5% accuracy.

Schallhorn (1957) reported that 95% of subjects had a kinematic hinge axis center within a radius of 5 mm from the arbitrary hinge axis center. Similarly, the relationship of the maxillary incisor to the arbitrary transverse horizontal axis was evaluated on 73
patients, and was noted that 89.04% were located within 5 mm of a mean distance of 100 mm from the arbitrary hinge axis to incisal edge (Kois, 2013).

Weinberg evaluated the use of an arbitrary hinge axis and stated that a negligible antero-posterior error in the magnitude of 0.2 mm was introduced at the second molar region when the axis location is within ±5 mm of the true hinge axis (Weinberg, 1961). He further explained that a gross error produced clinically, may not be due to error in hinge axis location or mounting procedures, but rather due to the centric relation record itself. Similarly, Arstad reported that an error of 0.2 mm was observed at the molar region as a result of 5 mm error in the location of the true hinge axis (Arstad, 1954).

Several researchers concluded that the arbitrary hinge axis did not coincide with the true hinge axis. Lauritzen (1961) concluded that only 33% of participants were within 5 mm of the true hinge axis. Similarly, Walker (1980) reported only 22% of participants had a true hinge axis within 5 mm of the 13 mm arbitrary location. Additionally, Palik et al (1985) clinically evaluated the arbitrary axis location in relation to the terminal hinge axis using earbow and the infraorbital notch as the third point of reference. A statistically significant difference was found in that the earbow recorded the arbitrary axis in an anterior location 92% of the time. Only 50% fell within the 5 mm radius zone mentioned in the literature. It was concluded that the earbow measurements were not statistically repeatable.

Earbows are also used to mount the maxillary cast to the articulator in the same orientation as the patient's (Chan, 2006). Three points of reference are required to determine the plane of orientation of the maxilla, two posterior to the maxillary arch and
one anterior. The posterior points of reference are the condyles or their equivalent; external auditory meatus; and the anterior point of reference can be either an anatomical landmark or a specific measurement established scientifically and recommended by system manufacturer. Different systems use distinctive third point of reference to transfer the relation and mount the maxillary cast to the articulator. The condylar guidance may be influenced by the selection of different anterior point of reference or by the type of articulator design. An increase or decrease in the protrusive condylar guidance inclination on the articulator can result as a consequence to variation in the supero-inferior position of the casts on the articulator. This makes the reliability of these anterior reference points in orienting the maxilla on the articulator questionable (Prajapati et al, 2013). Interestingly, Craddock and Symmons (1952) reported that when they studied mounted casts with 2 mm error in anteroposterior, superio-inferior and lateral positions, it was found that resulting occlusal errors were negligible and might not be detected clinically. It was thus concluded that casts may be mounted at an average distance from the THA and discard the facebow.

**Mandibular movements**

Mandibular movements are classified into three types. Diagnostic test movements are obtained by directing the patient in making left and right lateral excursive and protrusive movements from centric relation position. Functional mandibular movements are usually expressed as natural movements associated with mastication, swallowing, yawning, and speech. All other movements that are associated with clenching, grinding, and tapping are considered as para-functional activities (Rahn and Heartwell, 1993).
When reconstructing a patient’s dentition, the prosthodontist’s goal is to replicate on the articulator the maxillo-mandibular relationships that accurately reproduce mandibular border movements of the patient, in order to accurately examine occlusion, diagnose interferences, plan and execute treatment. Registration of horizontal and sagittal movements of the patient allows determination of maximum cusp height and fossae depth with proper placement of occlusal ridges and grooves. This will allow the construction of a prosthesis that is in functional harmony within the boundaries of a patient’s mandibular movements, free of interferences, and simulate the patient’s dentition in form and function. In many cases, it is permissible, and often advantageous, to alter the occlusal vertical dimension (OVD) to achieve a more stable relationship of mandibular teeth with their maxillary opponents. Dawson (2008) explained that such changes in OVD self-adapt to the original OVD without harm or discomfort if the occlusal contacts are in harmony with centric relation (CR).

The Pantograph

The pantograph is a device that is used to record patient mandibular border movement using a total of six tracings, in order to program fully adjustable articulators so that the movements of the articulators accurately simulate the border movements of the patient (Curtis and Sorensen, 1986). The pantograph can also be used as a diagnostic instrument to compare and evaluate the degree of reproducibility of jaw movements in relation to established norms, as well as to assess the severity of dysfunction (incoordination). The variation from normal can be determined based on the resultant incoordination of the tracings (Shields, 1978).
An electronic pantograph (Pantronic) was used by Payne to compare the condylar determinants of 55 patients. It was found that the values for the condylar determinants; horizontal condylar inclination (HCI), immediate mandibular lateral translation (IMLT), and progressive mandibular lateral translation (PMLT) were variable within a large range. For that reason, Payne emphasized the importance of identifying an individual’s condylar determinants rather than relying on average values for articulator programming. (Payne JA, 1997).

Several authors studied the influence of mandibular movements on the occlusal morphology of posterior teeth and described the changes in the cusp angle and groove direction due to the variation in condylar determinants (Chang et al, 2004; Rahn and Heartwell, 1993; Okeson, 2003; Dawson, 2006). Several factors contribute in determining the cusp inclination, as well as the depth and direction of the grooves. One factor is the inter-condylar dimension, which has an effect on cusp paths. Wider inter-condylar distance resulted in working and balancing cusp paths positioned more distal on the mandibular teeth and more mesial on the maxillary teeth. Other factors that also have an effect on the cusp paths are the Bennett movement and the timing of this movement. The more the side shift (Bennett movement) and the greater the side shift initially, the more mesial are the cusp paths on the mandibular teeth and the more distal they are on the maxillary teeth. Factors that have an influence on cusp height and fossa depth are related to the angle of the eminence as well as the curve on the eminence. Shorter cusps and shallower fossae are associated with lesser angles of the bony eminentia and less curved eminentia. Additionally, greater side shift requires shorter cusps and shallower fossae to prevent interferences and the lesser the side shift, the
longer the cusps must be and the deeper the fossae to provide proper support (Rahn and Heartwell, 1993).

Bernhardt et al (2003) conducted a clinical study to compare arbitrary and kinematic location of the transverse horizontal axis in mandibular movements with the electronic pantograph system (Cadiax Compact). Although the kinematic determination of the transverse horizontal axis was the most precise method, the arbitrary determination demonstrated acceptable reproducibility for both HCI and PMLT. For that reason, it was concluded that the measurements of the Cadiax Compact system, based on the arbitrary axis, could be reliably used for articulator programming.

**Dental Articulators**

Dental articulator is a mechanical instrument that represents the TMJ and jaws, to which maxillary and mandibular casts may be attached to simulate some or all-mandibular movements (GPT-9, 2017). Articulator has an essential roll in diagnosis, treatment planning, and in the fabrication of dental prosthesis. Different designs of dental articulators were introduced to the profession. Mitchell (1978) presented the historical background of dental articulators through out the years. He described in his articles the differences between these articulators and the concepts that were followed by the inventors to design and modify their instruments (Mitchell, 1978).

Owing to the presence of different designs, attempts were made to classify these articulators. Different authors had proposed distinctive classification systems based on: (1) descriptive purposes (Anthony, 1942), (2) design of articulators (Beck, 1962), (3) concept associated with each articulator (Weinberg, 1963), and (4) type of records used
to set the articulator elements (Thomas, 1973). Since these classifications caused confusion, a simpler classification system was proposed by Rihani (1980). His classification was based on the articulator’s adjustment capabilities depending on the number of records accepted by the instrument. Articulators differ from each other in a sense that some accept more records and can be adjusted and customized more than others. The different registration records used to adjust the articulator include: (1) facebow record, (2) centric jaw relation record, (3) protrusive record, (4) lateral records, and (5) inter-condylar distance record. The classification divides the articulators into three categories. (a) Fully adjustable articulators that include articulators designed to accept all five records to program its elements. (b) Semi-adjustable articulators, and these include articulators that accept three records to adjust the instrument. These records include the facebow, the centric jaw relation, and the protrusive records. (c) non-adjustable articulators, which include articulators that were not designed to be adjusted to accept each of these three records (Rihani, 1980).

Celenza (1979) described the different types of articulators and which one to use based on the treatment provided. It was stated that simpler cases that involve a quadrant and/or use centric occlusion would be best treated with articulators that do not require eccentric registration. This is opposed to full mouth reconstruction cases where centric relation is necessary. In the latter case, a fully adjustable articulator is dictated. A classification for articulators was mentioned as well in Celenza’s article. This classification was presented in the section on "Articulators" in The International Workshop on Complete Denture Occlusion in 1972. It was based on the instrument
capability, intent, registration procedure, and registration acceptance. (Lang and Kelsey, 1972). The Classification of cast relators "Articulators" was described as follows:

**Class I.** Simple holding instruments capable of accepting a single static registration.

1. *Subdivision A* - Vertical motion only for convenience.
2. *Subdivision B* - Vertical motion is joint related.

Class I instruments are particularly suited for centric occlusion restorations. These are good crown and bridge or operative instruments. Key features are positive stops and locks at the mounted position.

**Class II.** Instruments that permit horizontal as well as vertical motion but do not orient the motion to the temporomandibular joint.

2. *Subdivision B* - Eccentric motion permitted is based on theories of arbitrary motion.
3. *Subdivision C* - Eccentric motion permitted is determined by the patient using engraving methods.

These instruments appear to be useful for the mounted position only. The eccentric movements permitted offer no advantage since they are not registered and are therefore inaccurate. The exception to this is the Subdivision C instrument.

**Class III.** Instruments that simulate condylar pathways by using averages or mechanical equivalents for all or part of the motion. These instruments allow for joint orientation of the casts and may be arcon or nonarcon instruments. All the instruments used as
examples in this class are arcon instruments, accept facebows, and have mounting plates for unlimited case load. Additional features are listed with the illustrations.

1. **Subdivision A** - that accept static protrusive registrations and use equivalents for the rest of the motion.

2. **Subdivision B** - Instruments that 'accept static lateral protrusive and use equivalents for the rest of the motion.

These instruments can fulfill the requirements for complete denture construction and also serve as good teaching instruments for occlusion and temporomandibular joint courses. The desirable features would be a good centric lock, progressive and immediate side shift controls, protrusive inclination, intercenter distance adjustment, a simple mounting procedure, a good sturdy design, and an arcon arrangement. The nonarcon design is included in the classification for historical reasons, not as a recommendation.

**Class IV.** Instruments that will accept three dimensional dynamic registrations. These instruments allow for joint orientation of casts.

1. **Subdivision A** - The cams representing the condylar paths are formed by registrations engraved by the patient.

2. **Subdivision B** - Instruments that have condylar paths that can be angled and customized either by selection from a variety of curvatures, by modification, or both. These articulators (the only ones properly named) are the instruments of choice. For complete reconstructions and as teaching aids for advanced occlusal studies. These instruments should hold adjustments, contain good centric locking
mechanisms, versatile incisal guide tables, and stable mounting features, and be precision engineered. (Lang and Kelsey, 1972; and Celenza, 1979).

This classification was adopted by the ACP as the current accepted classification of dental articulators, which reads:

"Articulators are divisible into four classes; Class I articulator: a simple holding instrument capable of accepting a single static registration; vertical motion is possible; syn, NONADJUSTABLE ARTICULATOR; Class II articulator: an instrument that permits horizontal as well as vertical motion but does not orient the motion to the temporomandibular joints; Class III articulator: an instrument that simulates condylar pathways by using averages or mechanical equivalents for all or part of the motion; these instruments allow for orientation of the casts relative to the joints and may be arcon or nonarcon instruments; syn, SEMIADJUSTABLE ARTICULATOR; Class IV articulator: an instrument that will accept 3D dynamic registrations; these instruments allow for orientation of the casts to the temporomandibular joints and simulation of mandibular movements; syn, FULLY ADJUSTABLE ARTICULATOR, FULLY ADJUSTABLE GNATHOLOGIC ARTICULATOR." (GPT-9, 2017)

The fact that several mounting techniques exist depending on the articulator devise used possesses an important question concerning the accuracy of mounting. The variation of the third reference point can be expected to influence (or alter) the location (or orientation) of the maxillary cast being mounted in relation to anatomical special position. Hence this study is designed to compare and evaluate the various devices and techniques currently available on the accuracy of mounting.
CHAPTER 3

AIM OF THE STUDY

The current study evaluated the difference between the protrusive and lateral movement angulations of the articulator obtained through analog programming using clinical records, and those generated electronically by the Cadiax Compact 2 device.

This study was designed to clinically evaluate the effect of mounting patient records utilizing different articulator systems on the reproduction of protrusive and lateral guidance for each articulator. Four different commercial articulator systems were compared, namely, Denar ‘Mark 330’, Hanau ‘Wide Vue’, Whip Mix ‘2240’ and ‘2340’, as well as the electronic pantograph (Cadiax Compact 2) and the electronically converted readings for each system, in addition to the newly introduced maxillary cast mounting device (Max Align). Therefore, this study collectively evaluated 10 different systems.

The null hypothesis tested in the current study was that the mounting method through any given articulator system and device had no influence on the resultant articulator settings expressed in the protrusive and lateral angles.
CHAPTER 4

MATERIALS AND METHODS

Materials and methods:

This study was approved by the Institutional Review Board application at The Ohio State University (2016H0430).

(A) Clinical Procedures:

A total of 10 healthy human subjects were randomly selected for this study from volunteer dental students at The Ohio State University College of Dentistry. The selection criteria were: healthy individuals without gender discrimination, who presented with no symptoms of temporomandibular joint disorder (TMD) and who were not undergoing orthodontic therapy. The scope of the study was explained to each participant, and any specific questions pertaining to the procedures were answered prior to obtaining consent form signatures from the volunteer students.

The following clinical procedures were performed for each individual: Impressions utilizing addition silicone Vinyl Polysiloxane putty impression material (Reprosil Putty, Dentsply) were made in stock trays for both maxillary and mandibular arches in order to fabricate four sets of stone casts. A putty impression material was chosen to minimize errors while duplicating cast sets. Tray adhesive was applied on the
tray before impressions were made. After polymerization setting, the impressions were cleaned and disinfected prior to laboratory casting in dental stone.

Widely used semi-adjustable dental articulators with different third point of reference were selected to be evaluated and compared in this study. This included: Denar Mark 330 where the third point of reference is located 43 mm superior to the incisal edge of the maxillary lateral incisor and lateral to the nose, Hanau Wide Vue which utilizes infra-orbital notch as the third point of reference, Whip Mix 2240 (curvilinear condylar path with preset Bennett angle) and Whip Mix 2340 (straight condylar path) which use the nasion as the third point of reference. In addition, the commonly utilized electronic pantograph (Cadiax compact 2) as well as the newly introduced digital photography mounting system (Max Align) were compared.

_Cadiax Compact 2_

After practicing several times with each participant the mandibular movements and successfully guiding each subject into centric relation (CR) position, the electronic pantograph (Cadiax Compact 2) was used to record the mandibular movements and generate programming values for all the respective articulator systems. A mandibular metal clutch with extraoral arm was loaded with occlusal registration material (Memoreg, Heraeus, Kulzer) and fitted on top of the mandibular teeth. Extreme care was taken so as not to extrude excess material to cover the occlusal surface of posterior teeth, which would potentially interfere with proper occlusion and mandibular closure. In accordance with the manufacturer instructions, the various component parts of the Cadiax Compact 2 system were assembled and attached to the patient utilizing the anatomical landmark
‘nasion’ as the third point of reference to orient the earbow. The system earbow was carefully mounted onto the subject’s head and the ‘inter-condylar distance’ reading shown on the earbow was entered into the computer (Figure 1).

The centric relation (CR) position was again verified several times, and set as reference starting point prior to initiating the electronic recording of mandibular movements. The movements were recorded and saved to the computer Cadiax software. Each movement was repeated 3 times. These were, protrusive, right lateral, left lateral, and maximum opening as well as habitual opening and closing (Figures 2,3). The data acquired from Cadiax compact served as a control for the study.

![Figure 1. Cadiax Compact 2 earbow mounted onto the subject.](image)
Figure 2. Subject performing mandibular movement.

Figure 3. Digital recording of the subject’s mandibular movement.
Max Align

The photo capturing mounting device (Max Align, Whipmix) was performed according to the manufacturer’s recommendations. A tablet computer (Samsung Galaxy) was mounted on a flat surface and was adjusted to align the patient’s face with the following reference points within a “ghost template” on the tablet computer:

1. The horizontal inter-pupillary line in the device with the patient’s inter-pupillary line.
2. The vertical midline on the device with the patient’s maxillary midline.

Following proper alignment of the patient’s facial features to coincide with the software’s ghost image, the patient’s picture was then saved. Clinical measurement of the patient’s mesiodistal dimension of the maxillary central incisor teeth was obtained and entered into the computer application software. This process was very important to ensure proper magnification of the stored image (Figure 4).
Thereafter, the tablet computer was mounted vertically onto the Max Align device. Each patient’s maxillary cast was placed onto a mounting table and adjusted in 3D to coincide with the projected image of the patient on the tablet screen. Once alignment of teeth is perfected, the upper member of the articulator is closed to secure the mounting position of the maxillary cast (Figure 5-8). The mounted cast is then removed and transferred to its respective articulator. In this study, the Denar articulator was the one chosen for mounting with Max Align (Figure 9).
**Figure 5.** Computer tablet with subject’s picture mounted vertically onto the Max Align device.

**Figure 6.** Adjusting maxillary cast onto mounting table to coincide with subject’s picture on the tablet.
Figure 7. Superimposed cast saved after alignment of teeth is perfected.

Figure 8. The upper member of the articulator is subsequently closed to secure the mounting position of the maxillary cast.
Subsequently earbow transfer records were accomplished for each subject utilizing the standard protocol for the remaining 4 different articulator systems. Occlusal registration material was used to secure the bite-forks intraorally for all systems.

1. Denar slidematic earbow:

A dot was marked with a red marker on the patient’s lateral side of the nose as (43 mm from the occlusal plane at the incisal edge position of the maxillary lateral incisor). This point represented the third point of reference for this system. After placing the fork on the occlusal surface of maxillary teeth and aligning it with the maxillary midline, the Denar slidematic earbow was attached and secured after leveling it with the third point of reference and the inter-pupillary line (Figure 10).
2. Hanau spring bow:

Infra-orbital notch was located before placing the fork in the patient’s mouth. Hanau spring bow was secured after it was leveled with the infra-orbital notch representing the third point of reference for this system (Figure 11).
3. Whip Mix earbow:

Since both articulators (Whip Mix 2240 and Whip Mix 2340) utilize the same earbow and mounted casts can be accurately interchangeable between these articulators, only one earbow transfer was made for each subject. The earbow was attached and secured to the fork after aligning it with the patient’s inter-pupillary line utilizing the Nasion as the third point of reference for this system (Figure 12).
In order to mount the mandibular casts and program the articulators, the following inter-occlusal records were obtained using occlusal registration material (Memoreg, Heraeus, Kulzer):

3. Right lateral excursive.
4. Left lateral excursive.
5. Protrusive.
(B) Laboratory Procedures:

Impressions were poured in type V dental stone (Die-Keen, Heraeus Kulzer) following recommended water/powder ratio by the manufacturer. Four sets of casts were made for each patient to be mounted on five articulator systems. Since mounted casts can be interchanged between Whip Mix ‘2240’ and Whip Mix ‘2340’ articulators only one set was mounted on Whip Mix ‘2240’ and transferred to Whip Mix ‘2340’ articulator in order to individually program each system.

The maxillary casts were mounted with mounting plaster (Whip Mix Corp.) on each articulator system utilizing its specific earbow transfer (Figure 13-15). The mandibular casts were mounted using CR inter-occlusal record (Figure 16-20).

Figure 13. Denar earbow transfer onto the Denar ‘Mark 330’.
Figure 14. Hanau earbow mounted onto the Hanau ‘Wide Vue’.

Figure 15. Whip Mix earbow mounted onto the Whip Mix ‘2240’.
Figure 16. Maxillary and mandibular casts obtained from Denar facebow mounted on Denar ‘Mark 330’.

Figure 17. Maxillary and mandibular casts obtained from Max Align mounted on Denar ‘Mark 330’.
Figure 18. Maxillary and mandibular casts mounted on Hanau ‘Wide Vue’.

Figure 19. Maxillary and mandibular casts mounted on Whip Mix ‘2240’.
Each articulator was programmed using direct protrusive and lateral inter-occlusal records obtained from each subject. Two trained investigators obtained readings separately on a random subset of 23 angles for reliability analysis.

The programmed articulator readings were compared to the readings obtained from the Cadiax electronic pantograph, as well as between each individual articulator type (in vitro bench test comparison).
Statistical Analysis:

Repeated angular measurements (protrusive and lateral angles) by the two trained investigators were first analyzed for reliability between observers, using the single score technique of Shrout and Fleiss (1979). Then the average of the two investigators was determined for each of these repeated measurements and this average was used for all subsequent analyses.

The obtained angular measurements were summarized by obtaining the means and 95% confidence limits for the ten subjects for each of the systems, movements and directions studied. The data was statistically analyzed using 3-way repeated-measures Analysis of Variance (ANOVA) with all interactions included in the statistical model. For the ANOVA, the methods of maximum likelihood estimation (Hartley H and Rao J, 1967) and the Satterthwaite degrees of freedom (Satterthwaite FE, 1946; Welch BL, 1947) (SAS MIXED Procedure; SAS Institute, SAS ® Proprietary Software 9.3, SAS Institute Inc., Cary, NC, USA) were used in order to account for any violations of normality or equality of variances. If statistical significance was found when the degrees of freedom were greater than one, Student’s t-tests with Bonferroni corrections (SAS MULTTEST Procedure) were used for pairwise comparisons of interest according to the introduced hypotheses in order to determine any statistically significant differences between the pairs being compared (overall α=0.05).
CHAPTER 5

RESULTS

For intra-rater reliability for single score repeated measurements repetition of the mandibular track inclination angles and the condylar movement pattern yielded excellent reliability according to Shrout and Fleiss (1979). The intra-class correlation was found to be 0.99.

The summary statistics for measured angles obtained from both the computerized pantograph and inter-occlusal record per each articulator system for all condylar determinants are presented in Table 1, and Figures 1 and 2.

A summary of the 3-way repeated-measures ANOVA is presented in table 2.
Table 1. Summary of means, Confidence Levels, and Standard Deviation

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Figure 21. Mean confidence limits comparison of right and left Bennett angles for all devices.
Figure 22. Mean confidence limits comparison of right and left condylar guidance for all devices
### Table 2. Summary of the 3-way repeated-measures ANOVA

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Comparing the protrusive to the lateral angle across devices was ignored due to the anatomic movement variations and the established range variations between protrusive angles and lateral (Bennett) angles, the statistical significance found in the interaction of the sides and the movements ($P=0.036$) was expected and was ignored in this study when comparing these angles to each other.

High statistical significance was found ($P<0.0001$) in the interaction between the movement and the system. Therefore, the paired test with Bonferroni adjusted equivalence $P$-value was done to compare between these systems for each movement. Table 3 shows pairs that were found to be statistically significance. Table 4 shows systems paired with the Cadiax Compact 2 system.
Table 3. Pairs that were found to be statistically significance

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<td>0.004</td>
</tr>
<tr>
<td>Protrusive</td>
<td>Hanau</td>
<td>Max Align</td>
<td>-9.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Protrusive</td>
<td>Max Align</td>
<td>WM 2240</td>
<td>7.5</td>
<td>0.002</td>
</tr>
<tr>
<td>Protrusive</td>
<td>Max Align</td>
<td>WM 2340</td>
<td>7.7</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>
**Table 4.** Systems paired with the Cadiax Compact 2 system

<table>
<thead>
<tr>
<th>Movement</th>
<th>System</th>
<th>_System</th>
<th>Estimate</th>
<th>P_value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral</td>
<td>Cadiax 2</td>
<td>Cad Denar</td>
<td>3.1</td>
<td>1.000</td>
</tr>
<tr>
<td>Lateral</td>
<td>Cadiax 2</td>
<td>Cad Hanau</td>
<td>-0.6</td>
<td>1.000</td>
</tr>
<tr>
<td>Lateral</td>
<td>Cadiax 2</td>
<td>Cad WM 2240</td>
<td>-1.9</td>
<td>1.000</td>
</tr>
<tr>
<td>Lateral</td>
<td>Cadiax 2</td>
<td>Cad WM 2340</td>
<td>2.9</td>
<td>1.000</td>
</tr>
<tr>
<td>Lateral</td>
<td>Cadiax 2</td>
<td>Denar</td>
<td>-6.6</td>
<td>0.013</td>
</tr>
<tr>
<td>Lateral</td>
<td>Cadiax 2</td>
<td>Hanau</td>
<td>-13.8</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Lateral</td>
<td>Cadiax 2</td>
<td>Max Align</td>
<td>-5.1</td>
<td>0.297</td>
</tr>
<tr>
<td>Lateral</td>
<td>Cadiax 2</td>
<td>WM 2240</td>
<td>-1.9</td>
<td>1.000</td>
</tr>
<tr>
<td>Lateral</td>
<td>Cadiax 2</td>
<td>WM 2340</td>
<td>-6.0</td>
<td>0.048</td>
</tr>
<tr>
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<td>Cadiax 2</td>
<td>Cad Denar</td>
<td>0.0</td>
<td>1.000</td>
</tr>
<tr>
<td>Protrusive</td>
<td>Cadiax 2</td>
<td>Cad Hanau</td>
<td>0.0</td>
<td>1.000</td>
</tr>
<tr>
<td>Protrusive</td>
<td>Cadiax 2</td>
<td>Cad WM 2240</td>
<td>2.8</td>
<td>1.000</td>
</tr>
<tr>
<td>Protrusive</td>
<td>Cadiax 2</td>
<td>Cad WM 2340</td>
<td>0.0</td>
<td>1.000</td>
</tr>
<tr>
<td>Protrusive</td>
<td>Cadiax 2</td>
<td>Denar</td>
<td>-0.4</td>
<td>1.000</td>
</tr>
<tr>
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<td>Cadiax 2</td>
<td>Hanau</td>
<td>6.8</td>
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<tr>
<td>Protrusive</td>
<td>Cadiax 2</td>
<td>Max Align</td>
<td>-2.9</td>
<td>1.000</td>
</tr>
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<td>Cadiax 2</td>
<td>WM 2240</td>
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<td>0.771</td>
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<tr>
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<td>Cadiax 2</td>
<td>WM 2340</td>
<td>4.8</td>
<td>0.482</td>
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</table>
In lateral extrusions, the Hanau articulator showed statistically significant difference when compared to all the other systems tested ($P$-values presented in table 3). Similarly, both Denar ‘Mark 330’ and Whip Mix ‘2340’ were found to be statistically different when compared to the Cadiax Compact 2 as well as to their system specific digital values generated by the Cadiax Compact 2 electronic pantograph ($P$-values presented in table 3).

In comparing paired values for protrusive condylar guidance, the Hanau articulator system, once again, showed statistically significant difference compared to Cadiax Compact 2 ($P = 0.009$), Denar ‘Mark 330’ ($P = 0.004$), and the Max Align device ($P < 0.001$). Although values obtained from the Max Align mounting device were comparable to other systems in the study, they were found to be statistically significantly different when compared to the values obtained from both Whip Mix 2240 ($P = 0.002$) and Whip Mix 2340 ($P < 0.001$) articulator systems.

The difference between the angles in protrusive movement obtained from the articulator through analog programming using clinical records and the ones generated electronically by the Cadiax Compact 2 were also analyzed. Amongst the systems tested, the Hanau articulator system was statistically different ($6.8^\circ$) $P = 0.009$. 

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CHAPTER 6

DISCUSSION

Based on the results obtained from this study, the null hypothesis; where the mounting method through any given articulator system and/or device had no influence on the resultant articulator settings expressed in the protrusive and lateral angles, was rejected.

Although statistical significance was generally noticed in the interaction of the sides and the movements ($P=0.036$), it was ignored throughout the study since dissimilarity in angle magnitude was expected due to the difference in type of movements. When comparing angles produced by protrusive movement with those created from lateral excursive movements, one can expect the first to produce a greater angle due to the absence of the medial wall that restrict the lateral movement (Rahn and Heartwell, 1993; Gysi, 1929; Engelmeier, 2010).

Generally, asymmetry between right and left angles obtained for each specific movement is not uncommon. However, this asymmetry is of no statistical significance, $P<0.879$ (Table 2). In this study, it was found that there is no statistical significance when right and left angles for each movement were compared among different articulator systems, $P<0.14$ (Table 2). This anatomical variation was heavily discussed in the prosthodontic literature particularly by Harry Page (1951a,b; and 1956) and followers of the tracographic theory, whereby each condyle was believed to function separately having
different axes of movement (Mitchell, 1978). This concept was generally not accepted by most authors who regarded the two condyles to function as having a common axis known as the terminal hinge axis or transverse horizontal axis (THA), (Rahn and Heartwell, 1993; Weinberg, 1961).

It was reported by Cheng et al (2004) the most consistent and valid readings were produced at the 10-mm condylotrack distance, for that they recommended this distance to be used in programming the articulators. This condylotrack distance is due to the minimum distance of 8 mm of movement required by the machine for the instrument to produce the recognition “beep”, which indicate that the movement has been properly recorded. However, this may cause the patient to produce unnaturally long and exaggerated movements. Lundeen (1973 and 1978) stated that 5mm was the average condylar pathway for recording the protrusive movement. In the current study, the 5 mm reading generated by the cadiax was selected for comparison due to patient ability to generate the movement.

Because statistical significant differences ($P<0.0001$) were found when comparing the different movements (both lateral and protrusive angles) across the different articulators, the paired test with Bonferroni adjusted equivalence $P$-value was indicated to evaluate the interaction between the movement and the system. This test was done to compare between the tested systems for each movement (Table 3), as well as to compare between the angles acquired by different systems to the non-converted values obtained by Cadiax Compact 2, which was the control group with the assumption that it accurately represents the patient (Table 4). Table 3 shows pairs that were found to be statistically significant when comparing different tested system to each other. Table 4
shows systems paired with the Cadiax Compact 2 system and the difference between these angles.

While all systems were found to be comparable in lateral excursions, significant statistical difference was found with the Hanau articulator when compared to all the other systems tested. Likewise, statistical difference was observed with both Denar ‘Mark 330’ and Whip Mix ‘2340’ when compared to the Cadiax Compact 2 as well as to their system specific digital values generated by the Cadiax Compact 2 electronic pantograph.

When analyzing the data in clinical perception, it was found that the digital pantograph consistently produced less Bennett angle compared to the one obtained from the analog clinical lateral inter-occlusal record (Table 3). Additionally, the Hanau articulator programing using the clinical records consistently produced larger Bennett angle compared to the other articulator systems studied.

Although Hanau showed significant statistical different from all of the compared devices used in this study in lateral extrusions, when compared in protrusive movement, it was only statistically different with Cadiax 2, Denar Mark 330 and Max Align, where the Hanau system produced a shallower condylar guidance when compared to these three systems.

Although Max Align was not significantly different when compared to Denar Mark 330 and Cadiax compact 2 generated values regarding protrusive condylar guidance, it is interesting to note that Whip Mix articulators (2240 and 2340) showed shallower condylar guidance compared to Max Align. These values may be the result of subjective mounting procedure whereby a 3-dimensional patient cast is mounted trying to match a 2 dimensional photographic image.
A very important aspect of this study was the assumption that the values obtained by the Cadiax Compact 2 electronic pantograph device (control) were regarded as the true representation of patient movements. In routine clinical practice, articulator setting or programming is normally accomplished through clinical intraoral analog records. Hence, the current study evaluated the difference between the lateral and protrusive movement angulations of the articulator obtained through analog programming using clinical records, and those generated electronically by the Cadiax Compact 2 device. Amongst the systems tested, the Hanau articulator system was statistically different regarding both parameters exhibiting bigger Bennett angle (mean difference 13.8°) and shallower protrusive guidance (mean difference 6.8°). This was in line with Hanau’s original research who found consistent Bennett angle ranging around 15° (Bue, 1993).

The reason for statistical difference of Hanau might be because it is a closed system when compared to the other systems tested in this study. Engelmeier (2010) described in his article some of the limitations of the Hanau articulator, which included inability of the articulator to accept lateral inter-occlusal records due to its lack of an adjustable intercondylar distance and the confines of its straight condylar guides. Engelmeier also mentioned how Hanau solved this dilemma by developing the “Hanau Formula” \[ L = \frac{H}{8} + 12 \].

Hanau (1930) claimed that the Model H was not designed to be an anatomic articulator; on the contrary, his intention was to provide a mechanism that enable clinicians to achieve an intraoral balanced occlusion by using a device capable of producing the equivalent movements of those of the mandible to the maxilla.
The differences in angles produced by the different mounting methods have an effect on the anatomy of the prosthesis to be fabricated. Other factors that also have an effect on the cusp paths are the Bennett movement and the timing of this movement. The more the side shift (Bennett movement) and the greater the side shift initially, the more mesial are the cusp paths on the mandibular teeth and the more distal they are on the maxillary teeth. Factors that have an influence on cusp height and fossa depth are related to the angle of the eminence as well as the curve on the eminence. Shorter cusps and shallower fossae are associated with lesser angles of the bony eminentia and less curved eminentia. Additionally, greater side shift requires shorter cusps and shallower fossae to prevent interferences and the lesser the side shift, the longer the cusps must be and the deeper the fossae to provide proper support (Rahn and Heartwell, 1993).

The limitations of this study included that only limited numbers of articulator systems were selected in this study based on their wide usage. There are verity of systems in the market that need to be tested before generalizing the outcome. The most recent device that has been introduced to the market for mounting casts (Max Align) utilizing different technology by means of 2-dimensional image to coincide with 3 dimensional casts. This poses a certain level of difficulty and a learning curve for both clinicians and dental technicians. Also, the record obtained by Max Align can only be used once for mounting, whereas the analog facebow record can be used to mount the case multiple times. Additionally, limitations in this study also include subjective angle determination between the two calibrated investigators based on the provided reference lines inscribed on each articulator.
CHAPTER 7

SUMMARY AND CONCLUSIONS

Ten healthy asymptomatic subjects were randomly selected from dental students at The Ohio State University to participate in this study. Digital and analog jaw tracking as well as inter-occlusal records were obtained for each subject to fabricate models and program the different mounting systems tested in this study. After programing the dental articulator for each system using the analog inter-occlusal records, values obtained were compared between different systems, and with the digital values attained from the Cadiax Compact 2 digital pantograph. All results were tabulated and statistically analyzed using 3-way repeated-measures ANOVA and Student’s t-tests with Bonferroni corrections.

Within the limitations of this study, the following were concluded:

1. Regarding protrusive movement, no statistical significance was found between the digital pantograph readings (Cadiax) and the clinical patients’ records except for Hanau articulator, which consistently produced shallower angles.

2. Although Max Align mounting device was found to be not significantly different than other systems, it showed statistical difference only in protrusive movement when compared to Whip Mix articulators 2240 and 2340.

3. In Lateral movement, significant difference was found between the following systems:
a. Hanau showed statistical difference when compared to all systems both digital and analog.

b. Both Denar Mark 330 and Whip Mix 2340 were found to be statistically different when compared to their digitally obtained values from the Cadiax 2 system.

c. Programed articulator settings using Max Align was generally comparable to the other systems tested in this study, although it did not use three points of reference.

d. Different mounting methods lead to different orientation of maxillary cast, which resulted in different protrusive condylar guidance values.

e. The Hanau articulator produced shallower condylar inclination angle and bigger Bennett angle compared to the systems studied.
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