The relation of semi-adjustable articulators to clinical outcome - A review

Mohammed Aleem Abdullah*, MDS and Abdullah R. Al-Shammery[I], BDS, MS

إن العامل الحاسم في نجاح وفشل الإجراءات السريرية لتعويض الأسنان غالباً ما يكون هو التطبيق الصحيح لمبادئ اطباق الأسنان .
هذه الورقة تستعرض الدراسات المخبرية والحيوية الستراتيجية المتقدمة والتي تحاول شرح قدرة المطابق شبه المتحركة والمستعملة في تطوير الاطباق .
هذه المعلومات يجب أن تمكن الطبيب من اختيار أفضل الأدوات المستعملة لتحسين النتائج السريرية ، تم استعراض الدراسات العلمية بالنسبة إلى عناصر المطابق السنية شبة المتحركة:
١ – آلية الممر اللقمي ٢ – المسافة بين اللقمتين ٣ – حركة القواطع الأماميةونوع قضيب الدلالة .
إن أسباب أخطاء الاطباق الإيجابية والسلبية في التعويضات السنية المرممة لفم المريض باستعمال مطبق شبه متحرك تم توضيحها وتوثيقها ويوصي باختيار المطابق التي تناسب الإحتياجات السريرية .

Success or failure of prosthodontic clinical procedures often relies on the proper application of the principles of occlusion. This article reviews in vitro and in vivo studies on strategies that attempt to explain the capabilities of semi-adjustable instruments in the development of occlusion. This critical review enables the clinician to choose the most suitable instrument to improve clinical outcomes. Scientific studies have been reviewed in relation to the following components of semi-adjustable instruments: (1) condylar-fossa mechanism, (2) intercondylar distance, and (3) anterior incisal guidance and type of incisal guide pins. Positive and negative restorative occlusal errors using semi-adjustable articulators are explained and documented. Recommendations are provided for the selection of articulators that meet clinical requirements.

Introduction

Dental restorations should be fabricated on an articulator that can accurately reproduce the mandibular movements in order to minimize the need for intraoral occlusal adjustments. Semi-adjustable articulators are commonly used for the fabrication of occlusal surfaces of crowns, fixed partial dentures, implant prostheses and conventional complete and removable partial dentures during diagnoses and treatment planning.

Numerous semi-adjustable instruments have been devised by prosthodontists since 1906.[1] In 1985, Martin and Gariot[2] surveyed 53 North American dental schools and reported that the articulators used for undergraduate instruction in prosthodontics and occlusion were, in order of popularity: Whip-Mix**, Hanau Arcon H2 158, nonarcon Hanau Model 96 H2, Hanau Radial Shift H-166+, and Denar Mark II++.

Ideally, a semi-adjustable articulator should simulate mandibular movements in three planes in order to develop occlusal morphology of restorations that permit the passage of opposing cusps without interfering with mandibular movements.[1] Anatomical determinants, recorded by interocclusal check records, are transferred to semi-adjustable instruments to program the mechanical components that control the movements and influence the occlusal morphology of restorations.[3-7] The greater the accuracy in reproducing mandibular movements, the less will be the occlusal correction required when the restorations are seated in the mouth. Recently, semi-adjustable articulators have been introduced with new features such as a radial shift mechanism, condylar motion analogs, and rear wall adjustments to improve the articulator's ability to receive interocclusal static eccentric records and simulate mandibular movements.[8]

The purpose of this paper was to review the functions and limitations of mechanical components that simulate mandibular movements in order to enable the operator to differentiate the weak and the strong attributes among various semi-adjustable instruments.

Condylar fossa mechanism

There are two types of condylar fossa mechanisms in semi-adjustable articulators. One consists of condylar spheres set in straight tracks called, sagittal condylar guidances. The condylar spheres are connected by a rigid condylar shaft corresponding to the transverse hinge axis of the mandible. The condylar shaft can move mediolaterally within their respective condylar spheres. These instruments are called shaft articulators.[9] Articulators of this type are Hanau 96 H2 and Hanau H2 158 (Fig. 1). In the second type,

Received 13 February 2001; Revised 12 June 2001;
Accepted 20 August 2001
*Associate Professor, Department of Prosthetic Dental Sciences, College of Dentistry, King Saud University, Riyadh, Saudi Arabia
[I]Formerly Professor, Department of Restorative Dental Sciences, College of Dentistry, King Saud University and President, The Saudi Dental Society, Riyadh, Saudi Arabia
Address reprint requests to:
Dr. Mohammed Aleem Abdullah
Department of Prosthetic Dental Sciences
P.O. Box 60169, Riyadh 11545
Saudi Arabia

**Whip Mix Corp. Louisville California
+Hanau Teledyne Buffalo NY
++Denar Corp. Anaheim, California

the condylar fossa mechansisms of the upper member are seated on the condylar sphere attached to the lower members on which they are free to move. Articulators of this type are Whip-Mix, Denar Mark II, and Hanau Radial Shift (Figs. 2, 3).

Fig. 1. Hanau H_2 158 articulator. The condylar spheres are connected by a rigid condylar shaft which can move mediolaterally within their respective condylar spheres.

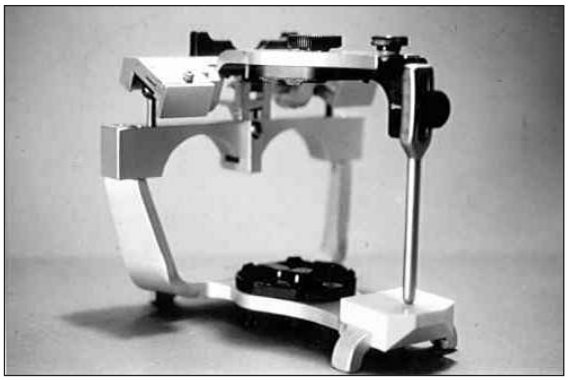

Fig. 2. The Denar Mark 11 articulator. The condylar fossa mechanism rests on fixed condylar spheres on which it is free to move.

Irrespective of the condylar fossa mechanism, the semi-adjustable articulators are classified as arcon and non-arcon instruments. The term arcon was coined by Bergstrom[10] from the words articulator and condyle. The arcon articulators have their condylar guidance mechanisms attached to the upper member and the condylar spheres to the lower member which are analogous to the arrangement in the human skull (Figs. 1,2,3). Articulators of this type are Hanau H2 158-1 through 158-6, Hanau Modular System 190 through 195, Hanau Radial Shift 166-1, Denar Mark II, and Whip-Mix. The non-arcon articulators have their condylar assembly attached to the lower member and condylar guidance mechanisms to the upper member, such as the Hanau 96 H2.

Studies have shown[10,12] that with an arcon articulator, a constant relationship always exists between the maxillary occlusal plane and the condylar guides in any eccentric positions of the upper member. Therefore the distance between the hinge axis and mandibular teeth in the articulator remains the same as found in the patient's mouth. Also, the reproduction of mandibular movements is more accurate than with a non-arcon instrument and a harmonious occlusion is more easily achieved. Contrarily, Weinberg[13] and Beck[14] concluded that arcon and non-arcon articulators produce the equivalent movements, and they further stated that clinically the arcon concept has no advantage.

Fig. 3. The Hanau modular system 194 articulator with fixed 11 cm intercondylar distance and adjustable radial shift guidance.

Intercondylar distance

The distance between the centers of the two condyles is described as the intercondylar distance. The more closely the articulator's intercondylar distance replicates that of a patient the more accurately the teeth are related to the vertical axes of the condyles. The ability of these articulators to duplicate the path of lateral movements is directly related to an accurate reproduction of the distance between each tooth and the vertical axis of each condyle which corresponds to the radius of rotation[15] (Fig. 4). If the exact length of the radius is not reproduced on the articulator the resulting path of movement of the supporting cusps traversing the central fossae of the opposing teeth will cause an occlusal error (Fig. 5). Furthermore, several investigators have reported that an instrument with a fixed intercondylar distance will not accept lateral check records from most patients and therefore, cannot be programmed accurately.[3-5, 10,15-16]

Articulators are built with either a fully adjustable or semi-adjustable intercondylar distance mechanism. The Hanau 130 and Hanau Modular System 195 series has a fully adjustable

intercondylar mechanism in which the condylar posts can be moved mediolaterally to increase or decrease the intercondylar distance in order to reproduce the patient's intercondylar width. Instruments with semi-adjustable intercondylar mechanisms such as the Modulular Hanau 166-1 may be adjusted to four different positions; 100 mm, 110 mm, 125 mm and 140 mm. According to Keshvad *et al.*[17] one additional use of intercondylar distance measurement is that the distance between right and left canines and first molars of both the arches can be determined and used in the arrangement of teeth in complete dentures.

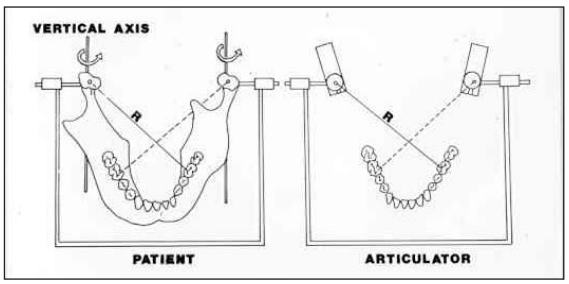

Fig. 4. Distance between each tooth and vertical axis of the condyle, R. It represents the radius of rotation of patient's mandible (left) and articulator member (right).

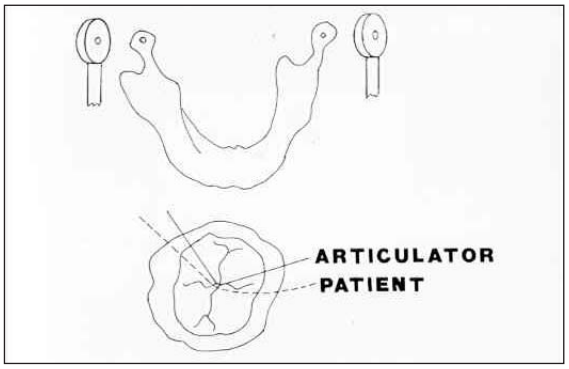

Fig. 5. Top, the intercondylar distance of the patient is smaller than that of the articulator. In the patient's mouth, the direction of the ridge and groove is mesial, whereas in the articulator, it is distal (bottom).

Protrusive condylar guidance

As the mandible moves forward, both condyles move forward and downward. The inclination of the superior wall of the condylar guide on the articulator simulates the protrusive condylar path and provides the protrusive condylar guidance. The influence of protrusive condylar guidance on occlusal morphology has been widely reported.[8,13,18] In semi-adjustable instruments, the superior wall of the protrusive condylar guidance may be straight or curved with average anatomical values. The average condylar path follows a curvature with a radius of approximately 0.75 inch (19 mm).[13] The difference between a straight condylar path and the apogee of a curved condylar path is 0.4 mm, (Fig. 6). A difference of 0.4 mm in the protrusive condylar path will produce 0.1 mm negative error in molar cusp height at the second molar.[13] Hanau Modular System articulators 190 through 195 are available with a wide range of curve protrusive condylar paths of 13 mm, 19 mm, and 25 mm radii, thus, the operator can select a radius according to the requirements of the patient.

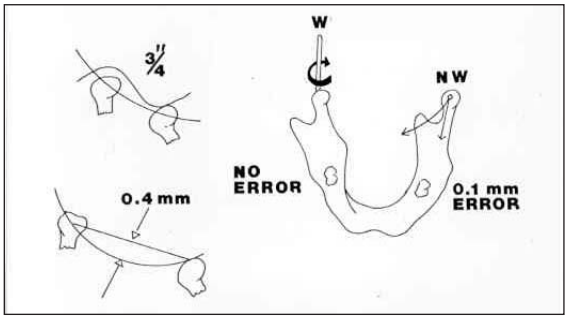

Fig. 6. Left top, average condylar path follows a curvature with a radius of ¾ inch. Left bottom, the difference between straight and curved condylar path is 0.4 mm. Right, occlusal error at 2nd molar due to lack of provision for Fisher angle in the articulator.

Lateral condylar guidance

During lateral movements of the mandible, the non-working condyle translates forward, downward, and medially guided by the neuromusculature and superior wall of the glenoid fossae. Anatomically, the path of the non-working condyle is steeper than the protrusive condylar path inclination by approximately 5^0.[13,18] The difference between the path of the non-working condyle and protrusive condylar path inclination is called the Fischer Angle (Fig. 6).[19] In the semi-adjustable articulators, the two inclinations are equal and there is no provision for a Fischer Angle. According to Weinberg,[13] if lateral check records have not been used, it is desirable to increase the protrusive condylar guidance by 5^0. Failing to accomplish this may cause a cusp incline negative error of 2.5 degrees and a cusp height negative error of approximately 0.1 mm at the second molar (Fig. 6).

During lateral movements of the mandible, the condyle on the working side is called the rotating condyle and the non-working condyle is referred

to as the orbiting condyle. As the orbiting condyle moves downward, forward and medially, its path is essentially divided into two components, immediate side shift and progressive side shift. In the immediate mandibular side shift, the orbiting condyle moves essentially straight medially as it leaves centric relation at the beginning of the lateral jaw movement[20] (Fig. 7). Since the teeth are not separated or only slightly separated when this movement occurs, the presence and degree of immediate side shift influences the occlusal morphology of natural teeth as well as artificial teeth. Following the immediate side shift, the orbiting condyle changes direction more or less abruptly to follow a more anteriorly directed path.

The rotating condyle moves laterally and is guided by the rear and superior fossa walls. The rotating condyle path of movement has a principal effect on the working inclines of the cusp on the working side[15,18] (Fig. 8). The lateral rotating condylar path may be inclined upward or downward, backward or forward. The upward or downward inclination of the rotating condylar path in the coronal plane influences height of the

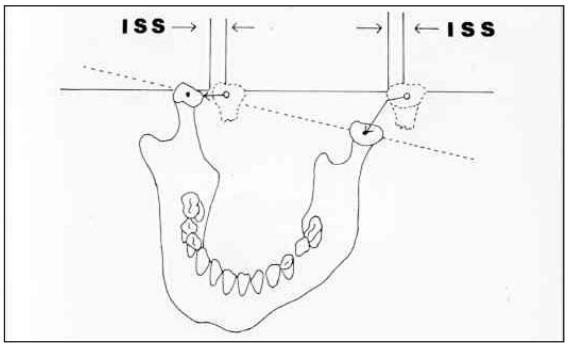

Fig. 7. During lateral movement of the mandible, the nonworking condyle (right side) moves downward, forward and medially and its path is divided into immediate side shift (ISS) and progressive side shift.

working cusp inclines.[15,18]

If the rotating condylar path is outward and upward, the height of the cusp inclines on the working side must be flatter. Whereas, when the rotating condylar path is outward and downward, the cusp height on the working side may be steeper (Fig. 8). The condylar mechanisms of the Hanau H2, Whip-Mix and Denar Mark II articulators cannot be adjusted to upward and downward movements of the rotating condyle.[15,18,21,22] Thus, it is reasonable to assume a negative or positive occlusal error in the patient's mouth if restorations are developed on semi-adjustable articulators.

Several types of semi-adjustable articulators with a wide range of intercondylar width adjustments and adjustable posterior, medial and superior fossa walls, have been introduced to simulate the immediate side shift with acceptable accuracy. The semi-adjustable instruments have two main types of condylar guidance

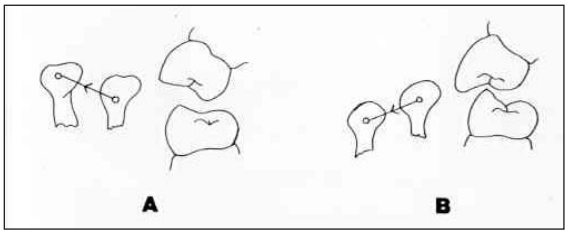

Fig. 8. A, if the rotating condylar path is outward and upward, the height of the cusp incline on the working side will be flatter. B, if the rotating condylar path is outward and downward, the height of the cusp incline on the working side will be steeper.

mechanisms.[23] One consists of moving condylar elements (two spheres set in an adjustable straight condylar track as found in the Hanau H2 series of articulators (Fig. 1). The other type has a condylar fossa mechanism that seats on the fixed condylar sphere on which it is free to move (Fig. 2). The latter type of condylar fossa mechanism is employed in Whip Mix, Denar Mark II and the Hanau modular instruments (Figs. 2,3). The capability to simulate the Bennett movement (side shift) by these two different types of condylar mechanisms is reported to vary.[15,22,23] In the shaft type instruments such as Hanau H2 models, the upper member has a rigid condylar axis and its two ends move medially and laterally within their respective condylar spheres. On carrying out lateral movements, the working condylar sphere must be held against the centric stop while the non-working side of the axis shoulder must continuously maintain contact with the moving non-working condylar sphere (Fig. 9).[23] The resulting gap between the working condylar axis shoulder and the working condylar sphere represents the amount of bodily shifts of the upper member of the articulator which is an approximate simulation of the immediate and progressive mandibular side shift.[23] Since the working condylar element remains firmly in contact with the centric stop acting as a fulcrum, the condylar axis moves backward and in a lateral direction,[15,23-25] whereas, during Bennett movement, the working condyle moves in any one of the nine directions.[15,22,31]

In the non-shaft instruments such as Whip Mix and Denar Mark II, the condylar fossa mechanisms of the upper members are seated on the condylar spheres which are attached to the lower member

on which they are free to move (Fig. 2). The angulation of the medial fossa wall to the sagittal plane is adjustable and is set for the progressive

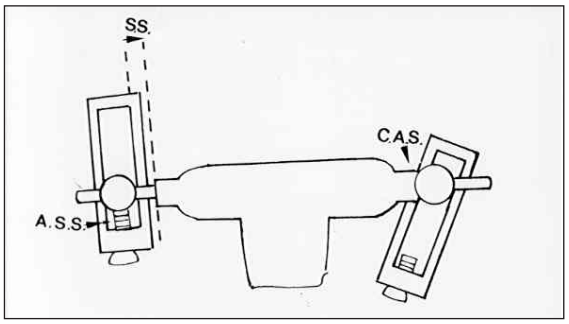

Fig. 9. Schematic representation of Bennett movement (SS) recorded by Hanau H_2 articulator. A.S.S. anterior screw stop (centric stop); C.A.S. condylar axis shoulder; S.S. side shift.

side shift (Bennett angle) by means of lateral check records. In order for the non-working condylar sphere to maintain contact with the medial wall of non-working fossa, the upper member must move bodily by a small amount towards the non-working side. The bodily side movement must occur with the superior and posterior wall of the working fossa maintaining contact with the working condylar sphere. The gap between the working condyle sphere and the medial wall of the working fossa indicates the amount of lateral shift of the upper member. This bodily shift of the upper member provides simulation of the immediate plus the progressive

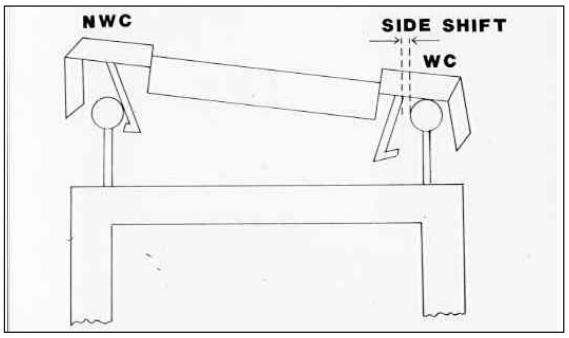

Fig. 10. Diagrammatic representation of Whip-mix articulator condylar guidance mechanism with a side shift. WC, working condyle; NWC, nonworking condyle.

side shift (Fig. 10).

Hickey *et al.*[26] stated that the design of the condylar housing in the Whip Mix allows the working condyle to move in a lateral direction only during Bennett movement. Heartwell,[12] Knap and Zeibert,[16] Belle *et al.*[5] concluded that the Whip Mix articulator will not accept all lateral check records with accuracy. Aull[18] explained that the condylar element of the Whip Mix articulator is bounded posteriorly and superiorly by fossa walls and only four directions of movement for the working condyle are possible. These are straight lateral, lateral and downward, lateral and forward and lateral forward and downward Therefore, he concluded that the simulation of the Bennett movement by this instrument is limited. To overcome this limitation, the Hanau Modular 194 and Denar Mark II instruments have an immediate side shift path set to the average anatomical inclination which is out and backward 25 degrees in relation to the frontal plane (Figs. 11, 11A). Abdullah[3] reported 87% acceptability of lateral interocclusal records for the Hanau Modular 194

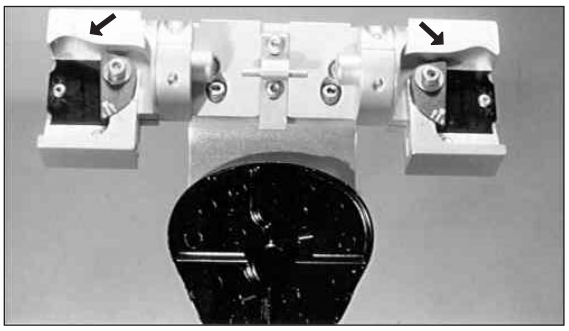

Fig. 11. The Denar Mark II articulator showing condylar guidance mechanism with a side shift path preset to the average anatomical inclination out and backward 25 degrees in relation to the horizontal plane (arrows).

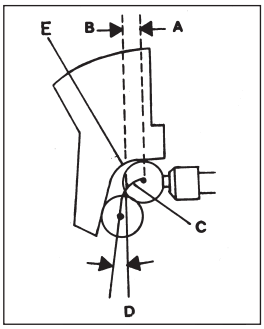

Fig. 11A. Schematic representation of condylar guidance. A and B, a 3 mm immediate side shift; C, curve path; D, progressive Bennett angle, and E, curved posterior wall of condylar guidance.

articulator and 80% for whip Mix articulator.

Anterior or incisal guidance

Several designs of anterior guidance tables are available. The anterior guidance consists of two components, the incisal pin and the table. The table may be classified as a mechanical or a

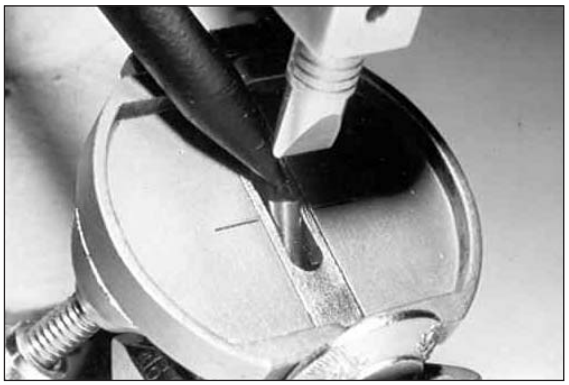

Fig. 12. The offset incisal pin on Hanau articulator.

customized anterior guidance system.

Incisal pin

The types of incisal pins are (1) straight (2) curved and (3) off set pins.[9] Articulators with straight pins are incapable of accepting alterations in vertical dimensions because by raising or lowering the incisal pin, the contact at the center of the incisal table will be lost (Fig. 1). The curved pin holder on the Denar Mark II (Fig. 2) and the off set pin on Hanau 2 (Fig. 12) permit change in vertical dimension without altering the central position of the incisal pin on the table.[2,19,27-30]

Incisal guide table

The mechanical incisal guide table consists of protrusive and lateral components (Fig. 1). The working tooth guidance, whether it is canine guidance or group function, govern the lateral protrusive component of working movement and is simulated by raising the lateral wings of the mechanical incisal guidance table.[19,20,23,26] The mechanical Schulyer incisal guidance has a special device that may be used to develop freedom in centric occlusion (long centric)[27] as shown in Fig. 12.

When natural anterior teeth are present, a custom anterior guidance can be provided by fabricating an anterior guidance jig of acrylic on the anterior guidance table. The customized anterior guidance table provides curved surfaces rather than flat planes. The flat planes of the mechanical incisal guide table allows only limited contact between the anterior teeth whereas, curved planes that are develop in acrylic resin follow the guiding surfaces of teeth and provide more accurate contacts and freedom in centric occlusion if it is present in the natural dentition.[27] The recent mandibular movement studies provide evidence that anterior guidance influences the working condylar path and supports the hypothesis that anterior guidance and condylar path are dependent factors.[28]

Discussion

When an articulator is used in the analysis of occlusion and development of occlusal morphology of restorations, it is desirable to understand its design, capabilities and limitations.

Certain semi-adjustable instruments are capable of approximating the patient's intercondylar distance with small, medium and large settings, thus allowing the vertical axes of mandibular rotation on the articulator to correspond more closely to those of the patient. According to Aull[18] the small and medium settings appear to reproduce the patient's intercondylar distance more accurately than the larger intercondylar distance range.

Investigators have reported that the working condyle has a tendency to move more backward, upward and laterally as the intercondylar distance increases.[24,25] Thus, large intercondylar distance duplication may be even more critical in the development of occlusal morphology.[31] Some of the latest semi-adjustable articulators such as Hanau Modular Series have a fixed intercondylar distance of 90 mm and the manufacturers claim that the adjustable posterior wall of the condylar housing compensates for the lack of intercondylar adjustments. This theory has been mathematically tested but not clinically proven.[21,22]

The working condylar movements should be considered when restoring occlusal morphology of posterior teeth with group function. Many investigators have reported that the posterior wall of the condylar housing controls the direction of the working condyle during lateral excursions.[3,21,22] However, Schulte *et al.* and Proschel *et al.*[31] stated that superior wall inclination significantly influences the working condylar movement and that the rear wall inclination has less influence. They further stated that harmonious occlusion may be developed without reproducing the exact rear wall angulation of the working condylar fossa.[31]

The working condyle in the patient includes both anteroposterior, and superoinferior components of movement in addition to the direct lateral side shift during lateral mandibular excursion.[16,18] Semi-adjustable articulators cannot be adjusted to upward and downward movement of the rotating condyle.[15,18,21-22] It is therefore,

reasonable to expect a negative or positive occlusal error in the patient's mouth at the time of try-in of a prosthesis. A slight negative error may not be ideal. However, it is acceptable when disclusion of posterior teeth is planned. Schulte *et al.*[29] and Proschel *et al.*[31] have suggested that if the patient's working condyle moves upwards and laterally in a frontal plane, increased anterior disclusion is required to prevent the supporting cusps of the maxillary posterior teeth from interfering with the lingual cusps of the mandibular teeth. If the working condylar movement is lateral and downward in the frontal plane, the effect of the anterior guidance appears to be less important. However, recent studies on mandibular movement provide evidence that anterior guidance influences the working condylar path and that the two factors are considered to be dependent.[28]

Since a high degree of accuracy cannot be achieved in semi-adjustable instruments to reproduce intercondylar distance, posterior, superior and medial fossa walls and the path of the immediate side shift movement, discrepancies in the occlusal morphology of restorations may be expected. However, understanding the limitations of instruments and the need for intraoral adjustments is a definite step towards developing better restorations. Cobot[6] argued that rather than prolong chairside time for prosthetic treatment, the use of an appropriate semi-adjustable articulator both enhances the quality of completed restoration, and saves on chairside time.

Recommendations

From a clinical standpoint, the immediate and progressive side shifts of the mandible are important to develop correct width of central grooves of posterior teeth in group function. Therefore, an articulator with an immediate side shift pre set for an average inclination out and backward 25 degrees may be more appropriate. However, if an anterior guidance technique is used for full mouth reconstruction, restoration of a few teeth with implants or a fixed partial denture requiring alteration of the vertical dimension of occlusion or freedom in centric (long centric) a mechanical Schuyler incisal guidance or an incisal pin with a curvature may be appropriate.

References

1. Starcke EN. The history of articulators: Early attempts to reduce mandibular movements. J Prosthodont 2000;9:51-56.
2. Martin DS, Gariot E. Articulators used in North American Dental School. J Dent Educ 1985;49:710-711.
3. Abdullah MA. A study of acceptability of lateral interocclusal records by a mandibular articulator . J Prosthet Dent 1995;74:408-411.
4. Gatson ML, Bardy RD, Varmilyea SG. A study of acceptability of lateral interocclusal record by Hanau H2 articulator. J Prosthet Dent 1985;53:252-256.
5. Bell LM, Matich JA. A study of the acceptability of lateral records by the Whip-Mix articulator. J Prosthet Dent 1977; 38:22-25.
6. Cobot LB. Using articulators to enhance clinical practice Br. Dent J 1998;184:272-27.
7. Dixon DL. Overview of articulation materials and methods for the prosthodontic patient. J Prosthet Dent 2000;83:235-247.
8. Hobo S, Shillingburg HT, Whittset LD. Articulator selection for restorative dentistry. J Prosthet Dent 1976;36:35-43.
9. Mitchell DL, Wilkie ND. Articulator through the years. Part II form 1940. J Prosthet Dent 1978;39:451-458.
10. Bergstrom G. On the reproduction of dental articulation by means of articulators, a kinematic investigation. Acta Odontol Scand 1950;9:207-212.
11. Beck HO, Morrison WE. Investigation of arcon articulators. J Prosthet Dent 1956;6:359-364.
12. Heartwell CM Jr, Rahn AO. Syllabus of complete dentures. Philadelphia, Lea and Febiger 1975:113.
13. Weinberg LA. An evaluation of basic articulator and their concepts, Part II: Arbitrary positional, semi-adjustable articulators. J Prosthet Dent 1963;13:662-669.
14. Beck HO. A clinical evaluation of arcon concept of articulator. J Prosthet Dent 1959;9:409-414.
15. Bellanti ND. The significance of articulator capabilities, Part I. Adjustable vs semi-adjustable articulators. J Prosthet Dent 1973;42:255-257.
16. Knop FJ, Ziebert GJ. Checkbite techniques in major oral reconstruction. J Prosthet Dent 1969;21:458-465.
17. Keshvad A, Winstanley RB, Hooshmand T. Intercondylar width as a guide to setting up complete denture teeth. J Oral Rehab 2000;27:217-226.
18. Aull AE. Condylar determinants of occlusal patterns. J Prosthet Dent 1965;15:826-846.
19. Lee RL. Anterior guidance. In Lundee HG, Gibbs CH, ed. Advances in occlusion. Boston: John Wright PSB Inc.1982;61-80.
20. Yang Y. Yatabe M, Sonda K. The relation of canine guidance with laterotrusive movements at incisal pin point and the working side condyle. J Oral Rehab 2000;27:911-917.
21. Finger IMF, Tanaka H. The new semi-adjustable articulator, Part III. An investigation of capability of the Hanau X-51 articulator. J Prosthet Dent 1977;37:310-319.
22. Tanaka H. The teledyne articulator system 154 as

applied to complete denture construction. Dent Clin North Am 1979;23:289-303.
23. Gross MD, Mathews JW. Occlusion in restorative dentistry. Technique and Theory. Edinborough, Churchill Livingstone, 1982;102.
24. Hobo S. A kinematic investigation of mandibular border movement by means of an electronic measuring system Part II: A study of Bennett movement. J Prosthet Dent 1984;54:642-646.
25. Hobo S. A kinematic investigation of mandibular border movement by means of an electronic measuring system Part III. Rotational center of lateral movement. J Prosthet Dent 1984;52:66-71.
26. Marklund S, Wanman A. A century of controversy regarding the benefit or detriment of occlusal contacts on the mediotrusive side. J Oral Rehab 200;27:553-562.
27. Schuyler CH. Freedom in centric Dent Clin North Am 1962;13:681-687.
28. Hobo S. Twin tables technique for occlusal rehabilitation: Part I. Mechanism of anterior guidance. J Prosthet Dent 1991;66:299-303.
29. Schulte JKS, Wang SHJ, Erdman AG, Anderson GC. Working condylar movement and its effect on posterior occlusal morphology. J Prosthet Dent 1985;54:118-121.
30. Schulte JKS, Wang SH, Erdman AG, Anderson GC. Three dimensional analysis of the cusp travel during non-working mandibular movement. J Prosthet Dent 1984;53:839-844.
31. Proschel PA, Maul T, Moreneburg M. Predicting incidence of excursive occlusal errors in common modes of articulator adjustment. Int J Prosthodont 2000;13:303-310.