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Review Article

Fully Adjustable Articulators – A Narrative Review

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Abstract

Fully adjustable articulators are sophisticated mechanical devices designed to reproduce the individualized movements of the human mandible and the functional relationships of the temporomandibular joints. In contrast to semi-adjustable articulators, they permit more extensive individualization of articulator settings through the use of kinematic facebow transfers, interocclusal records, and pantographic recordings of mandibular movements. This review provides a comprehensive overview of the evolution, mechanical components, programming procedures, and clinical applications of fully adjustable articulators, with particular emphasis on their comparison with semi-adjustable articulators. The review also examines the accuracy, clinical efficacy, advantages, and limitations of fully adjustable articulators and discusses their contemporary relevance in complex occlusal rehabilitation and full-mouth reconstruction. Although fully adjustable articulators offer a higher degree of individualized adjustment and can reproduce selected aspects of patient-specific mandibular movements more precisely than less adjustable systems. Their clinical superiority is dependent on accurate clinical records, appropriate programming, operator expertise, and the treatment objectives. Their role in contemporary prosthodontics should therefore be considered in relation to the complexity of the rehabilitation rather than solely on the basis of the level of mechanical adjustability.

Keywords: Fully Adjustable Articulator; Temporomandibular Joint; Pantographic Recording; Denar D5A Articulator; Occlusal Rehabilitation; Evolution of Articulators; Articulator Comparison

Introduction

Fabrication of different types of prostheses involves both clinical and laboratory steps and requires simulating devices like articulators. Mechanical articulators were introduced first to represent jaws and temporo-mandibular joint with capability of functional jaw movements. Different relationships of the jaws are identified, registered and transferred to the articulator. By registering the relationship of maxilla to the inter condylar axis (the distance) using a face bow and transferring it to the articulator, the opening and closing function becomes almost similar. Then the maxilla and mandible are related at an established vertical distance and registered at the centric position. This relation is also transferred to the articulator so that the opening axis, maxillary cast and mandibular cast are inter related as seen in the patient. If a semi adjustable articulator is used, the condylar path can be programmed so that the articulator can perform protrusive and lateral excursive movements. With suitable adjustments, Bennet movement can be incorporated in the articulator with reasonable accuracy [1].

Classification of articulators

It is roughly estimated that more than 250 patents have been filed globally under dental articulating technologies. In 1840, the first patents for dental articulators were issued to two Philadelphia dentists: James Cameron on April 30th and Daniel T Evens on August 28th [2,3] (Figure 1,2).

Figure 1: James Cameron dental regulator (1).

https://fineartamerica.com/featured/dental-articulator-jon-neidert.html

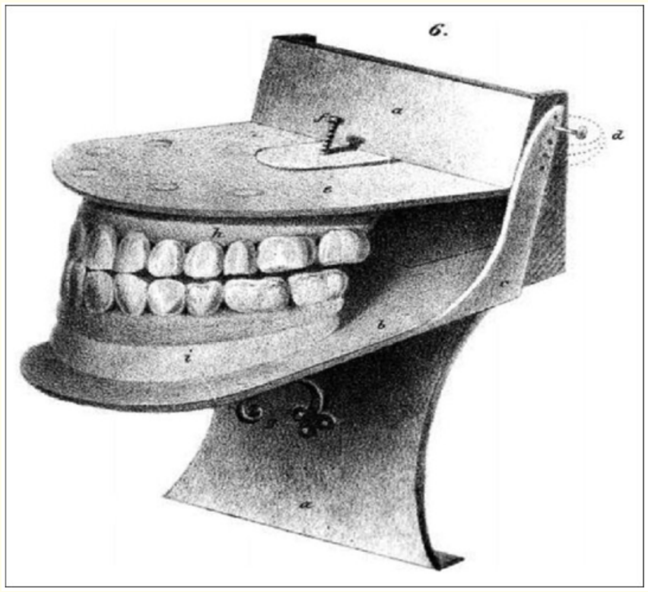

Figure 2: Evens articulator.

https://www.researchgate.net/publication/321145403_The_evolution_of_articulators_-_part_I/figures?lo=1

In the following 186 years, all the other patented articulators have come to the field with so much refinement, satisfying the scientific temper of the dental profession. Large number of articulators has necessitated a classification system that would help dental professionals to select an appropriate device for patient specific restorative needs. A common and widely accepted classification is based on the degree of adjustability like non adjustable, semi adjustable and fully adjustable articulators. As the adjustability increases, the articulators become capable of simulating the mandibular movements especially the protrusive and lateral excursions. The temporomandibular joint has a complex morphology and structure that fits efficiently for mastication and at the same time remains within the limitations of muscles and ligaments. If one or two teeth are to be restored too many adjustments are not required but a full mouth rehabilitation requires highly refined adjustments in the articulator set up. Many of the classification systems have limited clinical validity and very often confuse the operators. A logical classification of articulators was proposed by Awni Rihani in 1980 [4].

It is based on five records generally accepted in prosthodontics viz. (1) face-bow record, (2) centric jaw relation record, (3) protrusive record, (4) lateral records, and (5) intercondylar distance record. A fully adjustable articulator can accept all the five records where as a semi adjustable articulator can accept face bow, centric and protrusive records. A nonadjustable articulator can accept one or two of the following three records: face bow, centric or protrusive (Table 1).

Records	Fully adjustable articulator	Semi adjustable articulator	Nonadjustable articulator
Face bow	Yes	Yes	--
Centric jaw relation	Yes	Yes	Yes
Protrusive records	Yes	Yes	--
Lateral records	Yes	--	--
Inter condylar distance	Yes	--	--

Table 1: Rihani's classification of articulators.

Evolution of articulators

Reproduction of mandibular movements with precision and accuracy has always been a challenging task to the dental professionals and this context has led to the designing and production of simulating devices like articulators. The first-generation articulators incorporated average anatomical and functional values rather than patient specific records. Basic prosthodontic procedures utilized them but accuracy was limited because of the inefficiency in incorporating adjustability of incisal and condylar guidance. Semi-adjustable articulators were introduced subsequently with adjustable condylar guidance, allowing incorporation of selected patient records such as centric relation and protrusive or lateral interocclusal records. Fully adjustable articulators permitted extensive individual programming of condylar and incisal movements and which could reproduce complex mandibular dynamics with greater fidelity. However, their clinical use required sophisticated records, considerable time, and highly refined expertise of the operator.

The advent of digital dentistry led to the development of virtual articulators, in which digital dental casts are positioned within a computer-generated articulator and mandibular movements are simulated mathematically. Modern virtual articulators can integrate intraoral scans, facial scans, digital jaw-relation records and, in some systems, mandibular motion data. Virtual articulators offer advantages in visualization, data integration, treatment planning and CAD/CAM workflows, although accurate digital mounting and registration of mandibular movements remain important prerequisites [5-7].

Denar D5A articulator

The Denar D5A is a fully adjustable, arcon-type articulator designed to reproduce individualized mandibular movements using patient specific records. Developed as an advancement of the earlier Denar D4A system, it is regarded as one of the most versatile mechanical articulators fit for complex prosthodontic procedures. The articulator simulates the anatomical relationship of the temporomandibular joints by positioning the condylar elements on the lower member of the articulator and the fossae on the upper member.

Denar D5A has the capability to accept and reproduce mandibular movement data obtained from pantographic or computerized jaw-tracking systems such as Cadiax. The articulator permits adjustment of all significant determinants of mandibular movements, including horizontal condylar inclination, immediate side shift (Bennett movement), progressive side shift, superior wall inclination, posterior wall inclination, and intercondylar distance. The intercondylar distance can be varied from 90 to 150 mm, allowing precise simulation of individual patient anatomy.

The condylar fossae contain independently adjustable walls that can be modified to duplicate the patient's recorded condylar pathways. Removable medial and superior wall inserts permit customization when required. Additional features include an adjustable incisal guide table, custom step incisal table, long centric incisal pin, and a centric latch mechanism for secure positioning.

Denar D5A can reproduce complex mandibular movements and hence it is particularly useful in full-mouth rehabilitation, extensive fixed prosthodontics and research applications. Its use requires considerable clinical expertise and additional chairside time for recording and programming. Its individualized programming may facilitate the development of an occlusal scheme that more closely corresponds to the recorded mandibular movements; however, the clinical benefit depends on the accuracy of the records, transfer and programming procedures [8-13] (Figure 3).

Figure 3: Denar D5A articulator www.medicalexpo.comprod-whip-mix-corporationproduct-74510-660163.html.

Transfer of records from patient to Denar D5A

Facebow transfer

In Denar D5A articulator, the maxillary arch is related to the transverse horizontal axis using Denar slidematic facebow or any other compatible transfer system (Figure 4).

By recording the hinge axis and horizontal reference plane, face bow allows to record the spatial relationship of the maxillary arch to the selected transverse horizontal reference axis and reference plane, permitting transfer of this relationship to the articulator. For this, hinge axis locator and hinge axis face bow are required. In slidematic face bow, the external ear canal is used as the reference point with an ear piece facebow, which provides an arbitrary point of reference for each TM joint. The geometric relationship of the external auditory meatus to the TM joint is accommodated in the design of the facebow. Slidematic face bow allows transfer of inter condylar distance.

Figure 4: Denar slidematic face bow (Prestige dental).

Clinical Steps (Patient to Transfer Jig)

- **Prepare the Bite fork:** Apply a rim of bite registration material to the bite fork and have the patient bite into it to record the indentation of the upper teeth. Ensure the midline of the bite fork aligns with the patient's facial midline. In edentulous patients wax occlusal rims are used to stabilise the bite fork.
- **Align the Bow:** Assemble the vertical indicator rod to the ear bow and bite fork. Position the earplugs into the external auditory meatus and use the infraorbital pointer to align with the patient's anterior reference plane (e.g., 3 mm below the right pupil).
- **Lock and Detach:** Tighten all securing screws firmly. Loosen the ear bow to remove the bow assembly without disturbing the vertical rod and bite fork.
- **Create a Transfer Jig:** Secure the bite fork assembly into the transfer jig to maintain the spatial orientation after removing the bow [14].

Laboratory steps (Mounting on a Fully Adjustable Articulator)

- **Set the Articulator:** Calibrate the fully adjustable articulator (such as a Denar D5A) to the patient's recorded intercondylar distance. Set the condylar inclination and Bennett angle according to clinical pantographic or stereographic records.
- **Attach the Transfer Jig:** Mount the transfer jig onto the lower member of the articulator using the corresponding mounting table or accessory.
- **Position the Cast:** Seat the maxillary cast securely into the bite fork index.
- **Mounting:** Mix dental plaster and place it on top of the maxillary cast and on the upper mounting plate. Close the upper member of the articulator down into the mounting plaster, to connect the mounting plate and the cast. Allow the plaster to set fully before removing the transfer jig.

A benefit of using the Denar Slidematic Facebow is that multiple transfer jigs may be used with only one measuring bow. If required, mounting of the maxillary cast can be delegated to the laboratory, involving no loss of accuracy and no period of time without facebow transfer capability in the dental office. The laboratory can attach an articulator index to its own Denar articulator and mount the maxillary cast using only the bite fork assembly from the dental office. Each articulator index positions the bite fork assembly on any Denar articulator so that the relationship with the condyles recorded on the patient is accurately reproduced on the articulator. The incisor table is replaced with articulator index for this purpose. Once the mounting plaster has set, remove the transfer jig and replace the incisal table in the articulator [15,16] (Figure 5,6).

Figure 5: Transfering maxillary cast.

Figure 6: Mounting the maxillary cast.

Mounting the mandibular cast

Centric relation check bite record is obtained from the patient. Then the lower mounting plate is attached to the lower member of the articulator. The mandibular cast is hand articulated against the mounted maxillary cast in maximum intercuspation. Mark a line above the maxillary centrals and below the mandibular centrals on the gingival portion of the casts. Using a millimeter ruler or Digital Boley Gauge, measure the distance between the two lines. Now place the centric record on the maxillary cast and position the mandibular cast onto the centric record. Holding the casts with the record, measure the distance between the lines as done before. If the difference is 2mm more than the previous measurement, raise the incisal guide pin by 2mm. The casts with the centric record will be secured with wires and the mounting is completed. Once the mounting plaster is set, the casts are carefully separated from the centric record. The incisal guide pin is readjusted to obtain contact in centric relation (Figure 7,8a,8b).

Figure 7: Casts are hand articulated and markings measured.

Figure 8a: Incisal pin in ero position.

Figure 8b: Incisal pin adjusted to increase the height.

Recording mandibular movements

Mandibular movements are graphically recorded with Denar pantograph. 3D record of jaw pathways is used to calibrate the fully adjustable Denar D5A articulator. Denar pantograph provides a three-dimensional graphic record of selected mandibular border movements that can be used to program a fully adjustable articulator. The process captures temporomandibular joint dynamics for complex rehabilitations.

The set up includes metal clutches attached to the teeth with compound/acrylic resin/bite registration paste according to the design of the clutch. The face bow assembly consists of a maxillary bow and a mandibular bow which are attached to the clutches. The Denar pantograph utilizes six mechanical styli attached to the maxillary facebow. They are spring-loaded and designed to maintain constant, gentle contact with the recording tables while the patient guides their jaw through various border movements (protrusive, right lateral, and left lateral). Correspondingly six tracing tables are attached to the mandibular facebow. These tables are typically coated with a pressure-sensitive recording medium or specialized graph paper. One vertical and one horizontal tracing table are located on each side of the patient's face, over the temporomandibular joints – 4 numbers. Posterior vertical tables record the sagittal condylar inclination and the vertical path of the condyle during side shifts. The horizontal tables record the Bennett angle at the translating condyle and the immediate side shift at the pivoting condyle. The roles get reversed when the mandible moves to the other side. These track the precise pathways and rotational shifts of the condyle. A pair of horizontal tables is positioned below the eyes, near the anterior teeth/plane of occlusion. These graph the gothic arch and anterior jaw dynamics (Figure 9,10,11) https://www.slideshare.net/slideshow/pantograph-pptx/259073276.

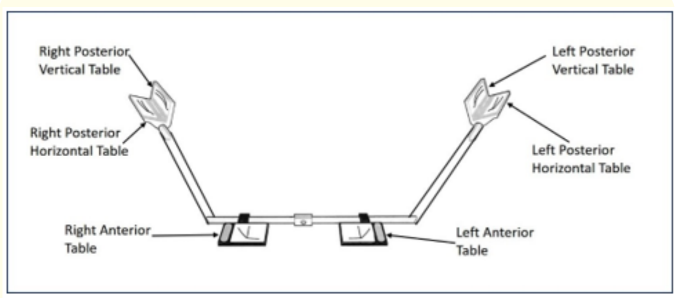

Figure 9: Assembly of tracing tables.

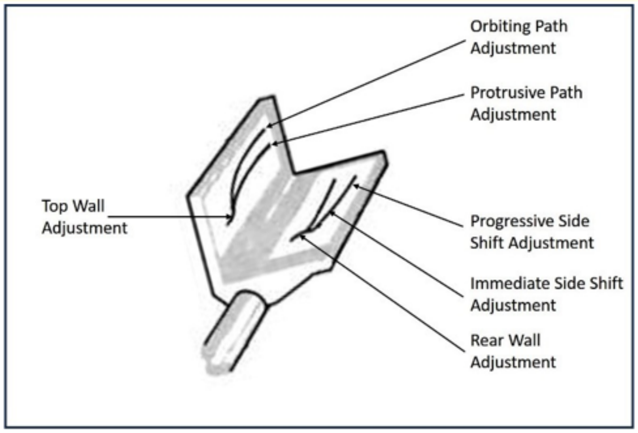

Figure 10: Posterior tracing table (left) and tracings.

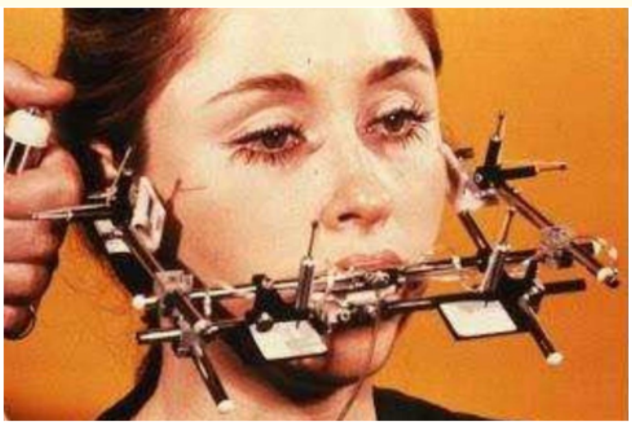

Figure 11: Pantograph assembly on the patient.

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Locating the Hinge Axis

Before tracing, adjust the condylar rods to locate the patient's Terminal Hinge Axis. Kinematic hinge-axis location is intended to identify the transverse horizontal axis around which the mandible rotates during terminal hinge movement. The styli attached to the face bow is positioned over the TMJ and the patient is asked to open and close the mouth. If the styli are away from the axis, it will arc. The styli are repositioned till the arcing is absent. Locating the hinge axis will ensure that the jaw opens and closes on its true anatomical centre. Simple vertical hinge movement will verify the axis position (Figure 12) https://pocketdentistry.com/2-diagnostic-casts-and-related-procedures/.

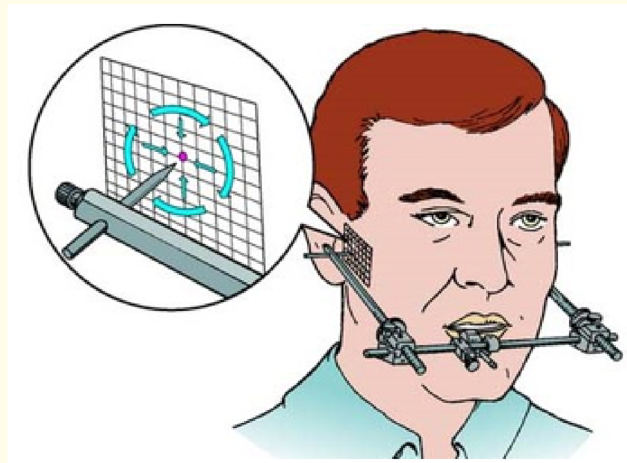

Figure 12: Locating the hinge axis.

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Tracing

The styli and the recording tables are attached and the patient is instructed to perform border movements. Protrusive forward movement is done to map sagittal condylar inclination. Lateral excursive movement of the mandible on both sides will capture the Bennett movement at the rotating condyle and the Bennett angle at the orbiting or translating condyle.

Transfer to the denar articulator

The spatial relationship of the clutches to the hinge axis is transferred to the articulator using a transfer jig. Then the recorded pantographic tracings are directly transferred to the articulator. Condylar controls of the articulator are adjusted until its movements copy the patient's physical tracing.

Preparation of Denar 5A articulator

Before transferring the pantograph from the patient, the articulator should be zeroed to the baseline configuration.

- Set condylar inclination to 30^0
- Set immediate side shift to 0 mm
- Set progressive side shift to 0^0
- Ensure all tracking walls – top, rear and medial – are unlocked and free to move
- Secure the pantographic assembly onto the articulator using Denar transfer jig and aligning it with hinge axis of the instrument.

Programming sequence

- Adjusting the protrusive path – Articulator is moved to protrusive position; attention should be given to posterior vertical tables and the condylar guide housing is moved up and down and the sagittal condylar inclination angle is finalized with the help of the stylus. The antero-posterior inclination of the superior fossa wall or fossa assembly can be adjusted from 0–60 degrees from the horizontal reference plane by loosening the adjustment lock screw. The scale for this adjustment is calibrated in five degree increments (Figure 13).

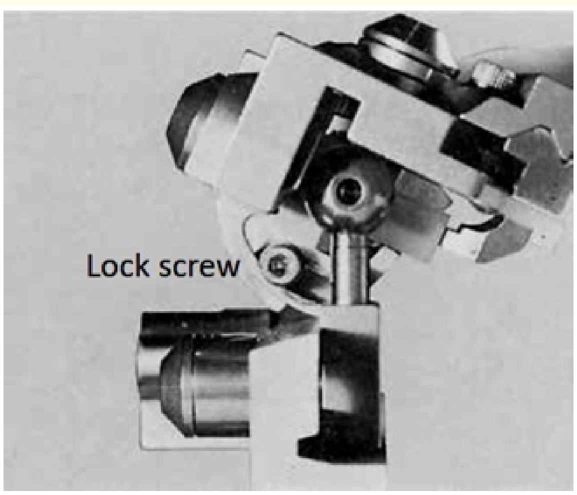

Figure 13: Adjustment of the protrusive path.

- Adjustment of non working condyle - Articulator is moved to the right lateral excursion to program the left condyle and vice versa. Attention should be given to posterior horizontal tables and the anterior tables. The medial fossa wall can be displaced medially by loosening the immediate side shift adjustment lock screw. The amount of the displacement and the amount of immediate side shift allowed is indicated on the vernier scale (Figure 14). The medial wall of the condylar housing is adjusted so that the stylus tracks the angled portion of the scribed line and this sets the Bennett angle. The progressive side shift adjustment affects the cusp height and ridge and groove position, primarily in the nonworking excursion. The condylar inclination adjustment affects the cusp height in the protrusive and nonworking excursion without affecting the working excursion.

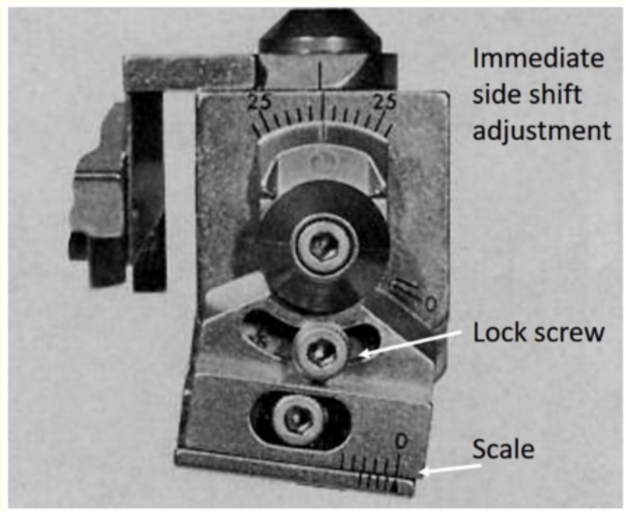

Figure 14: Immediate side shift adjustment.

- Adjustment for the working condyle – this is the condyle towards which the mandible is moving. If the mandible is moving towards the right side, the right condyle is termed as the working condyle and vice-versa. Attention should be given to the posterior vertical and horizontal tables of the working side. The working condyle moves backward, forward, upward or downward. The rear and top walls of the condylar housing are adjusted until the styli track the scribed lines (obtained from patient) faithfully (Figure 10). Changes in immediate side shift, intercondylar distance, and rear and top wall settings had effect on molar occlusal morphology. 0.2 mm change in the immediate side shift setting has the greatest effect on the occlusion, whereas a 5-degree change in the rear and top wall settings has the least effect.

- Verification and fine tuning – All the translatory movements (Protrusion, left lateral and right lateral) are repeatedly performed and observe all the styli whether they follow the scribed lines. After this all the locking screws are tightened securely [17-21].

Electronic pantograph

Pantograph is a three dimensional dynamic recording system of jaw movements used in programming fully adjustable articulators like Denar D5A. Pantograph consists of two face bows; one attached to the maxilla and the other to the mandible using appropriate clutches. One face bow holds scribing devices (styli) and the other recording tables. When the mandible moves, tracings are produced on the tables which are known as pantograms. Generally protrusive, right and left lateral excursions are performed to obtain the tracings which are then transferred to the articulator which is programmed by making the styli follow the tracings. Necessary alterations in the angulations of the walls of the condylar housing are made so that the styli follow the tracings faithfully. This system of programming is time consuming and complex. To make the process easier Denar developed 'Pantronic' an electronic pantograph.

Electronic pantograph serves as a vital diagnostic tool in modern digital prosthodontics by precisely tracking and recording complex mandibular movements. Unlike traditional mechanical pantographs, which rely on stylized analogue tracings and are highly operator-dependent, electronic versions utilize advanced optoelectronic motion systems, wireless sensors, or digital target tracking cameras to instantly capture lower jaw motion in three dimensions. These electronic systems record condylar paths, border movements, and maxillomandibular relations within seconds, translating the data into numerical control values. This high-fidelity kinematic data is then integrated into computer-aided design (CAD) software and robotic or virtual articulators to map a 4D dynamic representation of the patient's jaw. Ultimately, this digital approach minimizes diagnostic programming errors, streamlines the clinical workflow, and enhances the overall precision of complex dental restorations. Several electronic tracings can be made and measurements related to condylar movements can be found out through printouts and through comparison [22-25].

Electronic dental pantographs can capture the data faster and produce direct numerical values. However, studies have shown that they have mixed superiority over traditional mechanical systems. Mechanical pantograph uses physical styluses marking physical recording plates; electronic uses computerized sensors or styluses sending digital signals. Mechanical yields physical graphic tracings on paper/plastic sheets; electronic generates digital data, numerical condylar values, and computer graphs. While, electronic systems avoid manual tracing errors, certain opto-electronic devices struggle with precise axis location, and mechanical tracings often maintain high consistency and clinical reliability [26].

Discussion and Conclusions

A fully adjustable articulator (FA Articulator) is considered to be the most sophisticated mechanical instrument used in clinical prosthodontics. It also enjoys fairly good rating in providing accuracy in reproducing mandibular movements using individualised clinical records. Commonly used FA articulators are Denar D5A, Stuart articulator, TMJ articulator and Panadent FA articulator.

Each condylar housing can be programmed individually through the records obtained from the patient. Bennett angle can be customised. Immediate and progressive side shift can be adjusted according to the tracings obtained from the patient.

Adjustability of intercondylar distance based on the anatomic measurements obtained from the patient is a fine grade characteristic of the fully adjustable articulator and hence incorporates accuracy in cusp morphology and occlusal relationship. Three dimensional condylar movements are reproduced with fairly good accuracy. Sagittal, horizontal and frontal pathways can be customised in fully adjustable articulators.

Though kinematic is preferred, FA articulators can receive facebow records of different types. Both mechanical and electronic pantographs can be received by FA articulators and mandibular movements are reproduced with good accuracy [26-31].

The manufacturing quality of the articulator is good and without error and repeatability is ensured. Incisal guidance is customisable and can duplicate patient's anterior guidance. Good reproducibility of human mandibular movements makes FA articulator suitable for

- Full-mouth rehabilitation
- Extensive fixed prosthodontics
- Complex removable prosthodontics
- Occlusal reconstruction
- Research
- Teaching and postgraduate training

Dental professionals acknowledge that articulators are essential because they simulate temporomandibular joint and jaw movements. Positional relationships of the jaws and teeth are replicated outside the mouth to help the fabrication of removable replacement dentures and fixed restorations. During the evolution of articulators, limitations were observed and hence upgradations were thoughtfully designed and added. Simple hinge articulators allowed basic opening and closing movements. Later mean value articulators were introduced which could perform translatory movements under standardised condylar and incisal guidance. The next stage was the introduction of semi adjustable articulators which had near human dimensions especially the inter condylar distance. It could be programmed with face bow transfer so that skull landmarks got related to the mounted casts. Condylar and incisal guidance were designed to be adjustable based on different registrations obtained from the patient. The condylar and incisal tracks were different from the anatomic pathways, in fact they were described as rectified. Fully adjustable articulators have arrived next in sequence. They could receive pantographic recordings and the condylar housings could be programmed individually. Intercondylar distance was adjustable (Table 2). Electronic pantographs provided direct readings in the form of printouts and the operators could easily programme the articulator. Virtual articulators are the most modern additions as a sequel to CAD/CAM and computer animations. Precise data if provided, can produce near natural restorations. Articulators are essential to replicate jaw mechanics, diagnostics and treatment planning, in bringing efficiency and accuracy and to provide efficient assistance in education.

Feature	**Mean value articulator**	**Semi adjustable articulator**	**Fully adjustable articulator**
Principle	Based entirely on average anatomical values	Based entirely on average anatomical values	Based entirely on individual patient records
Simulation of mandibular movements	Approximate	Fairly accurate	Highly accurate
Condylar guidance	Fixed	Adjustable	Individually programmed
Horizontal condylar inclination	Fixed average value	Adjustable from protrusive record	Individually adjustable using pantographic/electronic records
Lateral condylar guidance (Bennett angle)	Fixed	Adjustable	Individually programmed
Immediate side shift	No provision	Limited or absent	Fully adjustable
Progressive side shift	Not adjustable	Adjustable	Individually programmable
Intercondylar distance	Fixed	Fixed or preset	Adjustable
Condylar path	Fixed and rectified	Limited adjustability and rectified	Adjustable
Facebow transfer	Cannot receive	Can receive	Can receive / kinematic facebow preferred
Transfer of centric relation	Possible	Possible with accuracy	Possible with superior accuracy
Records for programming	Cannot receive any record	Receive face bow, protrusive and lateral records	Receive pantographic and electronic jaw tracking records

Reproduction of eccentric movements	Limited	Good	Good
Clinical accuracy	Limited	High	High
Ease of use	Easy	Moderate difficulty	Very complex
Chairside time	Minimum	Moderate	Maximum
Laboratory procedures	Simple	Moderately difficult	Difficult and complex
Operator skill level	Moderate	High	Advanced
Cost	Low	Moderate	Very high
Maintenance	Minimum	High	High
Common applications	Mounting diagnostic casts, undergraduate teaching, demo, simple removable dentures	Fixed prosthodontics, complete dentures, implant prosthodontics, full-mouth rehabilitation	Complex occlusal rehabilitation, gnathology, research, extensive implant rehabilitation
Representative brands	Gysi Simplex, Monson articulator	Hanau Wide-Vue, Whip Mix 2240, Denar Mark II, Artex CR	Denar D5A, Stuart Articulator

Table 2: Comparison of Mean value, Semi-adjustable and Fully adjustable articulators.

Fully adjustable articulators represent the highest level of mechanical adjustability among conventional articulators and have the greatest potential to reproduce an individual's mandibular movements because patient-specific determinants of mandibular motion can be incorporated. However, the available evidence does not justify an unequivocal statement that fully adjustable articulators are invariably the most accurate or that their use necessarily results in superior clinical outcomes. Their theoretical advantage in accuracy is dependent on the precision of jaw-motion recording, spatial transfer, articulator programming, and mechanical calibration. Fully adjustable articulators may be regarded as providing the highest potential for individualized reproduction of mandibular movements, rather than conclusively demonstrating the highest clinical accuracy in all prosthodontic situations. The available evidence more appropriately supports the statement that fully adjustable articulators have the highest potential for individualized accuracy, rather than conclusively establishing that they produce superior clinical outcomes [32-34].

Conflict of Interest

The authors declare that they do not have any conflict of interest.

CRediT Author Contributions

Conceptualization- K. Chandrasekharan Nair, Review of articles- Pradeep Dathan; Initial draft preparation: Pradeep Dathan, Bheemalingeswara Rao, Review and editing- K.Chandrasekharan Nair, Supervision-K. Chandrasekharan Nair.

All the authors have read and agreed to the published version of the manuscript.

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