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Review Article

Mandibular Movements – A Narrative Review

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Abstract

Human temporomandibular joint has complex kinematic capabilities. It is a diarthrodial joint capable of rotating along multiple axes and also can translate. The movements are limited by muscles, ligaments and tooth contact. The articular disc present inside the joint divides the joint space into cranial disco temporal joint and the caudally placed disco mandibular joint. Translation occurs in the former and rotation occurs in the latter. Understanding of the movements of the TMJ has led to the designing of articulators and fabrication of prostheses. This review has included details of the anatomic structure of TMJ and the sophistication of the functional movements. Findings of the recent research are also included.

Keywords: Rotation; Translation; Movement Planes; Border Movements; Envelope of Movements; Articulators

Introduction

Mandible is capable of making three dimensional movements which are perceived as complex and consists of two characteristic elements such as rotation and translation. The movements happen through temporomandibular joint, driven by the action of the muscles of mastication and mostly guided by the teeth and restricted by the ligaments. Functions like chewing, swallowing and speaking can also cause movements. They are known as functional movements. The key movements are opening, closing, protrusion, retrusion and side to side motions. Comfortable opening of the mouth happens between 45 to 50mm. This is measured between the upper and lower incisors and the vertical overlap is added to this value. In adult males the range is between 40-70mm and in females it is 40-67mm. If the measurement is below 40mm, the mouth opening is considered as restricted. Protrusive movement is between 4-10mm. Protrusion of 6mm is considered as clinically important to perform all functions and hence it is used as the bench mark to programme semi adjustable articulators. Lateral excursive movement ranges between 5-13mm on each side. During mastication the vertical opening happens between 18 to 90% of maximum opening.

Anatomy of the Temporomandibular Joint (TMJ)

The temporomandibular joint (TMJ) is a bilateral synovial articulation between the mandibular condyle and the temporal bone of the skull and that plays an important role in mandibular function like mastication, speech, swallowing, occlusal harmony and facial expression. Understanding of TMJ anatomy is essential for diagnosis and treatment of temporomandibular disorders, occlusal rehabilitation and for restoration of edentulism. The TMJ allows both rotational (hinge) and translational (sliding) movements and hence known as a ginglymoarthrodial joint. Diarthrodial joints are freely moving wherein the joint is encased in a fibrous capsule and the cavity (synovial cavity) is fluid-filled (Figure 1).

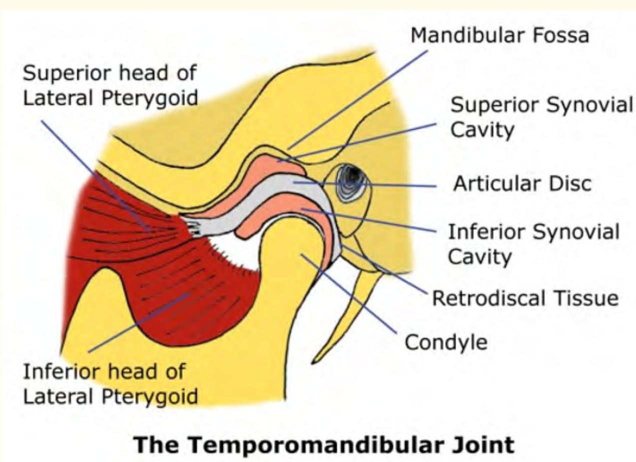

Figure 1: Structure of TMJ.
https://www.physio-pedia.com/TMJ_Anatomy

Mandibular condyle

Mandibular condyle serves as the posterior determinant of occlusion and is the movable component of the joint. The condyle is an ovoid structure with long axis oriented medio-laterally and slightly posterior. The morphology, position, and pathway influence mandibular movements and occlusal relationships. The articular surface is covered by dense fibrous connective tissue, allowing adaptation to functional stresses associated with occlusal changes and prosthetic treatments. Condyle determines hinge axis and terminal hinge movement; influences recording of centric relation and guides programming of articulator especially the condylar guidance settings.

Temporal bone (glenoid fossa)

The temporal bone contributes glenoid (mandibular) fossa which provides articulation but is not a primary load-bearing structure. Articular eminence is the main functional surface which guides condylar translation during protrusive and lateral movements. Inclination of the articular eminence determines sagittal condylar guidance which affects cusp height, occlusal morphology, and disocclusion patterns.

Articular disc

TMJ contains a fibrocartilaginous articular disc which divides the joint cavity into superior and inferior compartments. The disc has three distinct regions: 1. Anterior band, 2. Intermediate zone, 3. Posterior band. The central region of the disc is avascular and not innervated. But the periphery is richly vascularised and innervated. The disc helps in maintaining condyle disc relationship during movements, distributes load, absorbs shock and influences the centric relation position and occlusal stability. Anteriorly the disc is attached to the superior head of the lateral pterygoid muscle and its action causes protrusion and excursive movements. Posteriorly the disc is shaped into two laminae and gets attached to retro discal tissue. Disc displacement changes mandibular movement patterns, causes occlusal disturbances and associated joint sounds are observed. Collectively the changes in TMJ are termed as temporomandibular disorder.

Joint capsule

A fibrous capsule encloses the joint space and it is attached superiorly to the margins of the articular fossa and eminence and inferiorly to the neck of the mandibular condyle. The capsule provides structural stability. The inner synovial layer of the capsule produces synovial fluid which lubricates the joint, reduces friction and provides nutrition to the avascular articular tissues. The capsule allows movement but limits the range of movement to prevent excessive displacement. The capsule contains proprioceptive nerve endings which relay positional information of the jaw to the brain. The anterior and posterior areas of the capsule are more elastic and allow necessary translatory movements [1].

Joint spaces

The TMJ is a synovial joint divided into two distinct, non communicating compartments by the articular disc: 1. The superior disco temporal joint space located between the mandibular fossa/ articular eminence of the temporal bone and the superior surface of the disc. It is responsible for the sliding or translational movement of the jaw. 2. Inferior disco mandibular joint space, located between the inferior surface of the disc and the condyle of the mandible. Rotational or hinge movement happens in this space. The joint space is calculated to be between 1.5-2.5 mm or 2.4-3.57 mm [2,3]. Dimension of the space can change when the disc gets displaced. Joint space of male patients is observed to be higher than that of female patients. The number of female patients with TM disorder was higher than male patients. Older individuals have higher space than in younger individuals.

Ligaments of TMJ

Ligaments of the TMJ limit the movements of mandible, protect the joint structures and provide passive stability to the joint. Excessive posterior displacement and over extended opening are limited by the ligaments. There are three sets of ligaments present bilaterally:

- Temporomandibular (lateral) ligament – reinforces the lateral aspect of the capsule and limits excessive posterior, lateral and inferior movement of the mandible.
- Sphenomandibular ligament – It extends between the spine of the sphenoid and the lingula of the mandible. It acts as an accessory support and controls the depression of the jaw. The ligament protects the joint from excessive translation after 10^0 of mouth opening.
- Stylomandibular ligament – Connects the styloid process to the posterior margin of the angle of the mandible. It limits excessive protrusion and becomes taut during the protrusive movement [4] (Figure 2).

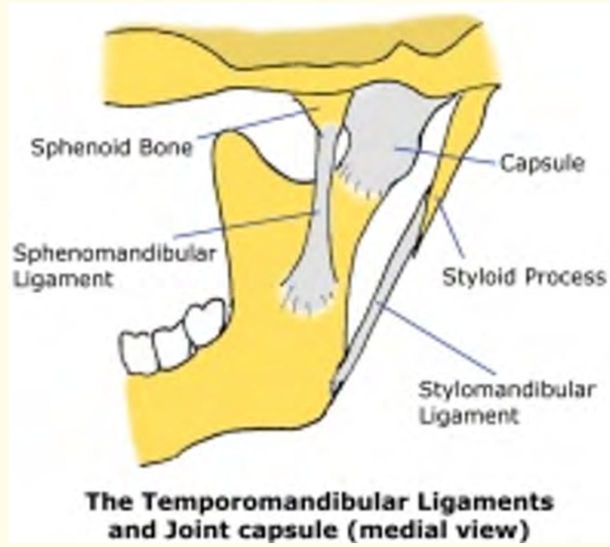

Figure 2: Ligaments of TMJ.

https://www.physio-pedia.com/TMJ_Anatomy

Muscles and TMJ function

Four pairs of muscles make direct functional contact with the TMJ and they include masseter, temporalis, medial and lateral pterygoids.

Masseter has multiple muscular layers and originates from the zygomatic arch and gets inserted on the lateral surface of the ramus of mandible and the coronoid process. When the masseter contracts, it causes powerful elevation of the mandible. When all the muscles of the jaw work together, they can exert a force equivalent to 25 kg on the anterior teeth and 90kg on the posteriors.

The temporalis originates from the temporal fossa of the skull and gets inserted on the coronoid process of the mandible. Primary action of the muscle is the elevation of the mandible.

Medial pterygoid muscle is a thick quadrangular muscle with two heads of origin. The deep head arises from the medial surface of the lateral pterygoid plate and the pyramidal process of the palatine bone. The superficial head arises from the maxillary tuberosity. The muscle gets inserted on to the rough triangular area of the medial surface of the ramus and the angle of the mandible. Primarily it elevates the mandible, assists in protrusion and enables side to side movement.

Lateral pterygoid muscle originates from greater wing of sphenoid (superior head) and from the lateral pterygoid plate (inferior head). The upper head inserts on the joint capsule and the superior portion of the pterygoid fossa of the of the neck of the condyle. The lower head gets inserted on to the pterygoid fossa. The upper head contacts the anteromedial aspect of the articular disc. Bilateral activation protrudes the mandible and unilateral activation causes contralateral deviation. Lateral pterygoid pulls the condyle forward during mouth opening. Dysfunction, such as tightness or spasms in this muscle, is frequently linked to temporomandibular disorders (TMD), pain, and clicking/locking of the jaw.

Innervation and blood supply of the muscles of mastication

All the four muscles are primarily innervated by the mandibular branch (motor) of the trigeminal nerve. Each muscle gets nerve supply with a designated nerve; Masseter – masseteric nerve, Temporalis – deep temporal nerve, Medial pterygoid – medial pterygoid nerve, Lateral pterygoid – lateral pterygoid nerve.

The blood supply for the muscles of mastication is derived mainly from the branches of the maxillary artery which is a terminal branch of the external carotid artery. External carotid has seven more branches.

Accessary muscles that assist muscles of mastication

Accessary muscles assist the primary muscles in stabilising the lower jaw, opening the mouth and control food position. This group includes buccinator, suprahyoid muscles (digastric, mylohyoid and geniohyoid) and infrahyoid muscles (sternohyoid, sternothyroid, thyrohyoid and omohyoid muscles). These muscles coordinate with the primary muscles to make complex movements during chewing and swallowing [5].

Mandibular movements in Indian subjects

Nilawar S., *et al*. have measured the range of mandibular movements in Indian individuals. The findings are based on the data obtained from 160 adults belonging to Bangalore and nearby areas.

The relevant measurements are given below:

- Mouth opening (passive): - 38.97 +/- 0.82 mm
- Mouth opening (active): - 51.94 +/- 0.44 mm
- Protrusion: -7.60 +/- 0.53 mm
- Anterior right lateral movement: – 7.24 +/- 0.33mm
- 5. Anterior left lateral movement: – 7.18 +/- 0.50mm
- Total medio lateral movement
- Incisor region: -14.38 +/- 0.78mm
- Right first molar: -8.17 +/- 0.43mm
- Left first molar: - 7.89 +/- 0.60mm

An interesting finding in this study is that after undergoing prosthodontic treatment, the mandibular movements get restricted [6].

Determinants of mandibular movements

Mandibular movements especially the range and path are determined by three factors:

- Posterior determinant consisting of two TMJs
- Anterior determinant consisting of guiding tooth contact and
- Neuromuscular control – the brain coordinates the muscles of mastication

Shape of the glenoid fossa and the slope of the articular eminence dictate the condylar glide. The angle at which the condyle descends is designated as condylar guidance. The overlap and the contact of anterior teeth guide the mandible during protrusion and lateral excursions. This is termed as incisal guidance and canine guidance. Neuromuscular control means the coordinating role of the brain on muscles of mastication to perform chewing and speaking. This includes the role of muscle spindles, proprioceptive engram and neuromuscular response to prevailing occlusal status. The posterior determinants are fixed and dentist cannot alter them. The anterior guidance provided by teeth can be modified to a certain extent by dental professionals. When tooth contact is modified the neuromuscular control also gets modified. The mechanoreceptors in the periodontium perceive occlusal contacts and provide feedback through a sensory feedback mechanism and guides mandibular movement. When occlusion is altered by professional intervention, the nervous system establishes a new engram or muscle memory for functional movement. When vertical dimension is altered electromyographic changes are resulted and which may lead to muscle fatigue or TMD related symptoms if the adaptation is not successful. Any alteration in occlusion can possibly change the muscular function related to mandible [7].

Axes and planes related to mandibular movements

Mandibular movements occur in a three dimensional space, through rotational and translational actions. Rotation occurs when the condyle moves around an axis and which happens in the inferior joint cavity. Three main axes have been identified viz. horizontal, sagittal and vertical. Horizontal axis (transverse/hinge axis) is an imaginary line passing through both the condyles around which opening and closing movements happen. Sagittal axis passes through one condyle in the antero-posterior direction and the contra lateral condyle moves up and down as part of translation. The third one is the vertical axis passing through one condyle and the contra lateral condyle moves forward and when reversed the condyle moves backward. The sagittal and vertical axes pass through one condyle (rotating) and the contra lateral condyle moves downward and forward (translating). This happens when the mandible makes lateral excursions. Mandible moves towards the side of the rotating condyle and it is known as the working side (ipsilateral side). Crushing of the food happens in the working side and the opposite side is known as nonworking. Various mandibular movements occur concurrently around one or more of the axes.

Mandibular movements are related to three anatomic planes: sagittal plane, horizontal plane and frontal plane. Sagittal plane is vertical and which divides head into right and left halves. Opening-closing movements and protrusion-retrusion movements and the inclusive Posselt's envelope of motion can be visualised in this plane. Horizontal plane divides the head into an upper and lower portion. This plane has to be viewed from the top to observe protrusion, retrusion and lateral excursive movements. Frontal (coronal) plane divides the head into front and back portions. Movement of the mandible can be viewed from the front while performing lateral movements (Figure 3,4).

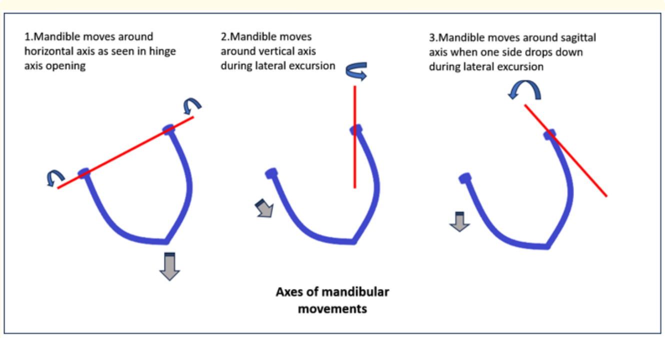

Figure 3: Axes of mandibular movements.

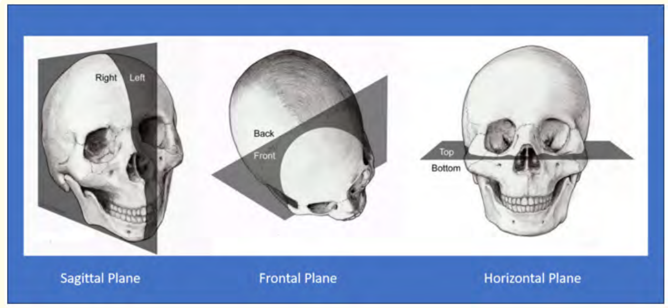

Figure 4: Planes of mandibular movements.

https://www.crossfit.com/essentials/anatomical-planes-axes

Border and envelope of mandibular movements

Border movements represent the extreme and maximum reproducible movements of the lower jaw functionally controlled by the TMJ, muscles and ligaments. Border movements can be recorded in the sagittal, horizontal and frontal planes. A composition of the three tracings will create a three dimensional space where all the mandibular movements can be included. This space was mentioned as 'envelope of motion by ULF Posselt in 1952. The essential movements include maximum opening, protrusion and lateral excursions [8-10].

After conducting an elaborate study on mandibular movements Posselt concluded that

- Habitual movements do not generally coincide with border movements
- Habitual movements show considerable variability in individuals than border movements
- The rest positions and intercuspal position generally differ from the retruded position of the mandible.

Posselt has made some other observations also: the movement area of the mandible in the sagittal and horizontal planes is characteristic of the individual but varies in different persons. However, the path of border movement is reproducible in the same individual. Another observation is that the temporomandibular joints (TMJ) are mainly responsible for limiting the border movements of the mandible.

The border position recorded in the sagittal plane has a similarity with a bird beak and the movements include rotation, translation, protrusion and retrusion. The posterior boundary of the polygon obtained indicate the terminal hinge to maximum opening. The superior boundary is dictated by the tooth contact viz. maximum intercuspation to anterior edge to edge position. From there it continues to maximum protrusion and thereafter to inferior boundary which indicate maximum opening. The posterior boundary starts with centric relation position which continues to rotational movement when the mouth opening is upto 25mm. This stage continues to further mouth opening caused by translation. It is calculated that the centre of rotation gets shifted from the condyles to the lingula in the second stage of opening. In the horizontal plane, a diamond shaped envelope tracing is obtained. This is made use of in the gothic arch tracing and thereby the centric relation position is verified in complete denture fabrication. In the frontal plane a shield shaped tracing is obtained for the envelope. All functional movements like chewing and speaking occur within the border limits [11] (Figure 5, 6).

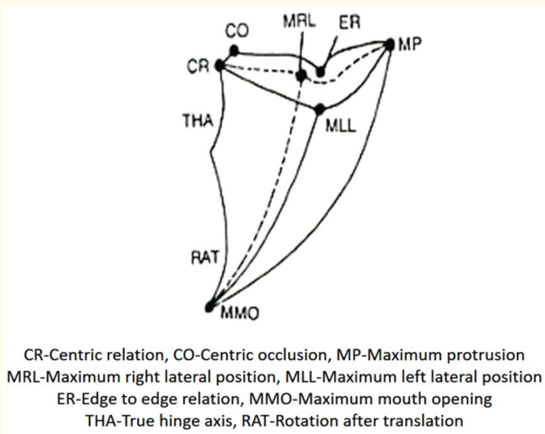

Figure 5: Envelope of mandibular motions.

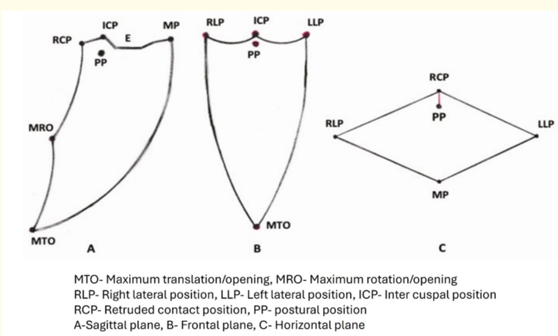

Figure 6: Border positions in diffrent planes.
https://www.nature.com/articles/s41415-022-5082-0

Some defined positions and occlusion

In a dentate individual, the analysis of occlusion starts with two positions viz. Intercuspal position (ICP) and Retruded contact position (RCP). In ICP, the upper and lower teeth occlude in maximum intercuspation. RCP can be defined as the initial tooth contact upon closure when the condyles are on pure rotation and in the superior and unstrained position of the glenoid fossae. So far RCP had an equivalent in Centric relation and ICP had an equivalent in Centric occlusion. RCP and ICP befit the dentate individuals and the equivalent terms for the fabricated prosthesis. In 90% of the population, ICP and RCP are not coincident. ICP is 1mm anterior to RCP. When an individual rolls back the tongue and reach for the most posterior part of the palate and close, a strange feeling occurs and the mandible slides anteriorly to the ICP. In fact, the slide gives a feeling of freedom otherwise known as long centric or freedom in centric. The freedom gives the ability to close in RCP or in ICP without encountering vertical changes or premature contacts. Because of the freedom, an individual gets an occlusal contact both at mastication (ICP) and at deglutition (RCP). In full mouth rehab the freedom is generated either in the anteriors or in the central fossae of posteriors [12].

Lateral excursive movements

During the process of mastication, mandible undergoes a side to side motion. These movements are complex and involve asymmetrical actions of the TMJ and the muscles of mastication on each side. When the mandible moves to one side, functionally the two sides perform different actions. Each side is designated differently like working side and nonworking side. The side towards which the mandible moves is the working side. The working side condyle rotates and acts as a pivot. The nonworking condyle moves forward, downward and medially. When the mandible moves to the right, that side performs as the working side and when the mandible moves to the left side, that side becomes the working side. The normal range of excursive movement is usually measured between 8-12 mm.

When the mandible moves to one side, the working side condyle gets shifted laterally which actually represents a bodily shift of the mandible. The working condyle really moves upward and backward in addition to the lateral shift. The average lateral movement is 1mm. Norman Bennet is credited with the identification of the lateral shift and hence known as Bennett movement. The nonworking condyle when viewed in the horizontal plane, it makes an angular movement which is in a forward, downward and medial direction and it is in an angle of 5 to 15 degrees. When viewed in the sagittal plane, the forward and downward translation of the nonworking condyle will be greater than for a protrusive movement and an angle is made between the two tracks and which is known as Fischer angle. In other words, the protrusive and mediotrusive tracks of the nonworking condyle makes an angle when viewed in the sagittal plane and that is termed as Fischer angle (Figure 7,8).

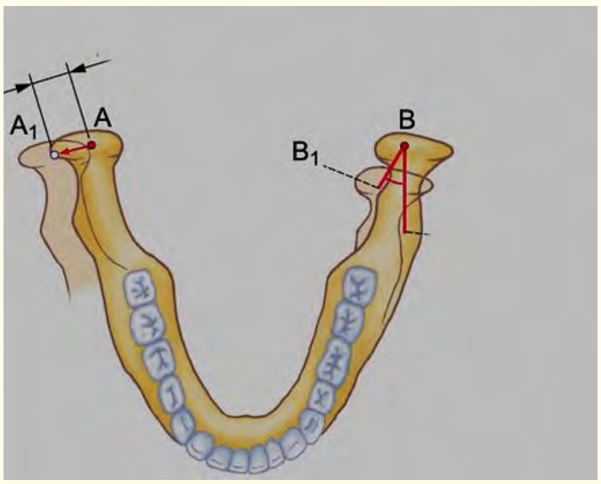

Figure 7: Bennett movement and angle.

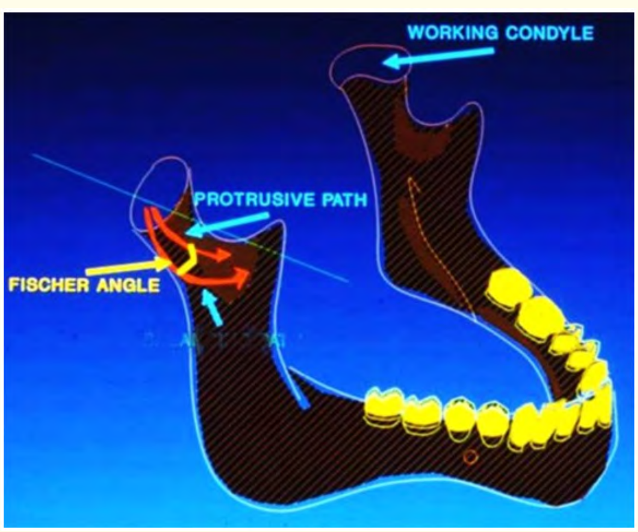

Figure 8: Fischer angle.

Can articulator simulate mandibular movements

The TMJ and the condylar elements of the articulator have certain differences. The walls of the glenoid fossa have a curvilinear architecture whereas the condylar track is rectified or planar. The disc in the TMJ is biconcave and made up of fibrocartilage. It divides the joint space into a superior and inferior compartments. The disc acts as a cushion, reduces stress, distributes pressure and enables smooth jaw movements. In the articulator there is a condylar element that revolves around an axis and moves in a track, the angulation of which can be adjusted to approximately match with the condylar movement path. On opening the mouth up to approximately 20-25 mm, the condyle rotates and beyond which translation also happens. But in the articulator, within the mechanical limits both rotation and translation are integrated and it is not related to opening range as in the TMJ. Bennett movement is observed in the working condyle and the movement is integrated within the entire bodily movement. In the articulator, the condylar housing is rotated axially according to the Bennett angle and the central axis of the articulator (hinge axis) gets pushed to simulate Bennett movement. Semi and fully adjustable articulators can be considered as an engineering marvel and a noble attempt to simulate an essential life function, the mastication. Accuracy of the articulator can be enhanced by observing essential cast mounting procedures like face bow transfer and jaw relation registrations.

The currently available articulators, in spite of their sophistication have limitations in reproducing mandibular movements. Azer S S and Kemper E have described a patient specific anatomic articulator using three-dimensional (3D) printing technology and patient’s cone beam computed tomography (CBCT) data.

Replicas of the condylar fossae, as well as condyles set at the correct intercondylar distance are made. The maxilla, maxillary teeth and edentulous ridge are printed with the correct spatial relationship to the condylar complexes and the Frankfort horizontal plane (FHP). The printed structures are then mounted onto a modified articulator frame to make it “anatomic.” This new custom anatomical articulator, which accurately simulates patient’s anatomical movements rather than relying on average values, represents the truly fully adjustable articulator. Many of the clinical steps like tracings and facebow mountings can be eliminated with the new system [13].

Conclusion

Prosthodontic replacement of teeth and restoration of function requires critical understanding of mandibular movements. To an extent the articulators simulate the functions of TMJ and it is improved by the findings of research. A simulated masticatory environment will enhance the functional efficiency of the designed prosthesis.

Conflict of Interest

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

Author Contributions

Conceptualization-K. Chandrasekharan Nair, Review of articles-Pradeep Dathan; Viswanath Gurumurthy, T. Mohan kumar, Initial draft preparation: Hemalatha Konka, Viswanath Gurumurthy, Pradeep Dathan, 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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