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Review Article

Mandibular Movements: A Comprehensive Review

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ABSTRACT:
Restorative treatment should be aimed at the achievement of smooth unhindered mandibular movements during function. The outcome should not result in an occlusal interference, nor should it lead to generation of excessive force on the teeth, the periodontal apparatus or the temporo-mandibular joints (TMJs). All members of the masticatory system should work in harmony and accommodate the changes in occlusal morphology of the finished restoration well. Central to the science of dental occlusion is the study of mandibular movements and positions or mandibular kinematics as it is sometimes called. An understanding of the patterns of mandibular motion undervarious conditions of guidance and restraint is important in most clinical situations, particularly in the diagnosis of occlusal problems, the recognitionand treatment of temporomandibular joint disorders, and the successful reconstruction of impaired occlusions. Mandibular movement occurs as a complex series of interrelated three-dimensional rotational and translational activities.
Key words: Mandibular Movements

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INTRODUCTION

One of the goals of restorative treatment is maintenance and/or reestablishment of a good dental occlusion when the treatment is completed. Therefore, restorative treatment should be aimed at the achievement of smooth unhindered mandibular movements during function. The outcome should not result in an occlusal interference, nor should it lead to generation of excessive force on the teeth, the periodontal apparatus or the temporo-mandibular joints (TMJs). All members of the masticatory system should work in harmony and accommodate the changes in occlusal morphology of the finished restoration well.[1]

Central to the science of dental occlusion is the study of **mandibular movements** and positions or ***mandibular kinematics*** as it is sometimes called. An understanding of the patterns of mandibular motion undervarious conditions of guidance and restraint is important in most clinical situations, particularly in the diagnosis of occlusal problems, the recognitionand treatment of temporomandibular joint disorders, and the successful reconstruction of impaired occlusions.[2]

Mandibular movement occurs as a complex series of interrelated three-dimensional rotational and translational activities. It isdetermined by the combined and simultaneous activities of both temporomandibular joints (TMJs). Although the TMJs cannot function entirely independently of each other, they also rarely function with identical concurrent movements. To better understand the complexities of mandibular movement, it is beneficial first to isolate the movements that occur within a single TMJ.[3]

Unlike natural teeth, prosthesis is either ankylosed to the bone, rests on the alveolar mucosa or on the supporting teeth. Lateral forces produced during mandibular movements due to the prosthesis can traumatize these supporting structures. Therefore, a thorough knowledge of mandibular movements is essential for prosthodontist to understand various aspects of occlusion before fabricating the prosthesis.[4]

OCCLUSION

Occlusion is the static relationship between the incising or masticating surfaces of the maxillary or mandibular teeth or tooth. It is a static position, as the mandible is not moving. On the other hand, the dynamic relationship of the mandible to the maxilla is known as an articulation, and indicates the contact relationship between the incising or masticating surfaces of the teeth during function and mandibular movements.

TEMPOROMANDIBULAR JOINT

To understand how the mandible moves, it is important to know the anatomy of the TMJ. Basically, the TMJ consists of the glenoid fossa, the condyle and the articular disc, which is located between the condyle and the fossa, and divides the joint into lower and upper compartments.

The **upper compartment** is located between the inferior surface of the glenoid fossa and the superior surface of the articular disc.
In this compartment only translational movements occur.

The **lower compartment** exists between the superior surface of the condyle and the inferior surface of the articular disc.
In this compartment only rotational movements occur.

A synovial membrane lines the joint capsule and produces the synovial fluid that fills these two compartments. The articular disc is composed of avascular fibrous connective tissue. It has three well-defined regions: the anterior; intermediate; and, posterior bands.

An important masticatory muscle is the lateral pterygoid muscle, which has two heads: the superior, and, inferior. The superior head is attached to the articular disc and the inferior head is attached to the neck of the condyle.

The posterior band of the disc is attached to two layers: a superior (elastic); and, an inferior (inelastic) layer. The two layers are collectively known as a bilaminar (retrodiscal) zone. The superior layer, being elastic, allows the disc to maintain its relationship with the condyle during translational mandibular movements. The inferior layer is inelastic; therefore, it maintains a normal relationship between the disc and the condyle. In the bilaminar zone blood and nerve supply are present. The joint is also composed of ligaments such as the stylomandibular and temporomandibular ligament. The joint is also surrounded by a capsule. The various structures of the TMJ are displayed in Figure 1.[1]

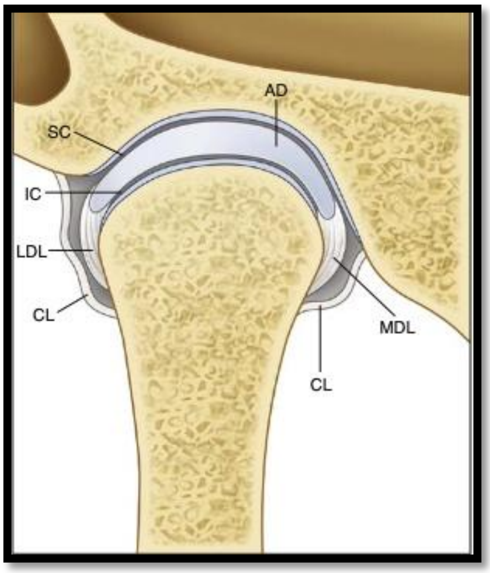


Fig 1: Temporomandibular Joint (Anterior View). The following are identified: AD, Articular disc; CL, capsular ligament; IC, inferior joint cavity; LDL, lateral discal ligament; MDL, medial discal ligament; SC, superior joint cavity

ARTHROKINEMATICS

The first movement on opening the mouth is a pure rotation around a horizontal axis through the two condylar heads. This occurs initially between the articular disc and condyle, in the lower joint. As this hinged motion is at its maximum, further opening occurs in the upper joint through a gliding or translatory motion of the condyle and meniscus gliding along the slope of the articular eminence. The gliding or translatory action may be executed unilaterally to produce a lateral deviation of the jaw. During right lateral deviation, the disc and condyle of the left TMJ slide downward, medially, and forward along the eminentia, whereas the right TMJ disc and condyle stay near its posterior position and rotates laterally around a shifting vertical axis. This transverse rotation of the condyle permits a slide slightly laterally, forward and downward on the articular slopes as rotation occur.

During protrusive and retrusive movements, the discs and condyles slide forward and downward and backward and upward, respectively. As indicated by Blaustein," the lower joints, bilaterally, working together, represent a hinge joint. The two discs act as a socket of the hinge in which the condyles rotate. The hinge movement occurs around a horizontal axis through the centers of the condyles. Normally, sliding in the upper joint and rotation in the lower joints are probably always combined, but the magnitude of one or the other at a time varies considerably.[5]

DETERMINANTS OF OCCLUSION

Occlusion and mandibular movements are controlled by three determinants (factors):

- TMJ, known as the posterior determinant;
- Teeth, known as the anterior determinant; and,
- The overall neuro-masticatory system.

POINT TO NOTE

Clinicians have no control over the posterior determinants (TMJs), as these are unchangeable, but they can change the anterior determinant (teeth) to good or bad. The neuro-masticatory system is required to deal with what we have restoratively created.

THE POSTERIOR DETERMINANT: TMJ

The influence of the TMJ on mandibular movements can be expressed by the inclination of the articular eminence (condylar inclination), the morphology of the medial wall of the glenoid fossa and the shape of the condyle. These three factors influence the mandibular movements, as they dictate the direction, duration and timing of mandibular movements and consequently affect occlusal morphology such as steepness of the cuspal angle and the direction of ridges and grooves.

The posterior determinant can be divided into vertical factors that affect the steepness of the cuspal angle and horizontal factors that affect the ridge and groove directions of the occlusal morphology.

For example: Condylar inclination denotes the angle at which the condyle descends along the articular eminences in the sagittal plane. The greater the angle of the articular eminence, the greater the steepness of the cuspal angle and the deeper the fossa (**Figure 2)**. When the mandible protrudes, the posterior part of the mandible drops down in a greater angle than if the angle of the articular eminence is less steep.

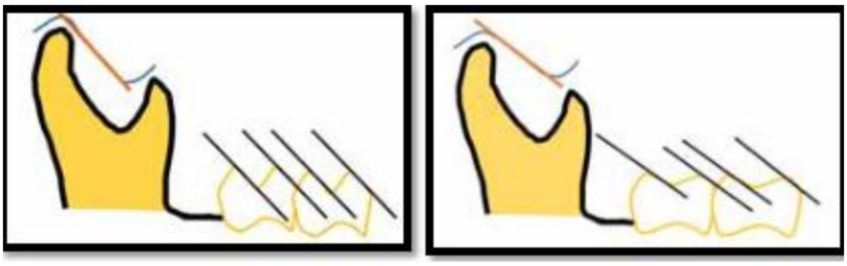


Fig 2: The greater the angle of the articular eminence, the greater the steepness of them cuspal angle and the deeper the fossa and vice-versa

A. THE ANTERIOR DETERMINANT: TEETH

The anterior determinant indicates factors within dentition that influence the occlusal morphology and the mandibular movements. The posterior teeth provide end-stop (vertical stop) of the mandible, while the anterior teeth guide the mandible into the maximum intercuspal position(MIP) and also in the right and left excursion, and in protrusive movements. However, in a patient with an anterior open bite, the influence of anterior teeth is lost and the posterior teeth may guide the mandible during the lateral excursions and protrusive movements.

POINT TO NOTE

The anterior determinant represents both anterior and posterior teeth and their effect on the mandibular movements, and not only anterior teeth.

ELEMENTS OF THE ANTERIOR DETERMINANT

1. Incisal guidance (vertical and horizontal overlap of anterior teeth).
2. Occlusal plane.
3. Curve of Spee.
4. Curve of Wilson.

1. **INCISAL GUIDANCE**
   Incisal guidance indicates the effect of the contacting surfaces of the maxillary and mandibular anterior teeth on the mandibular movements. This guidance forms an angle with the horizontal plane. It is represented by the vertical (overbite) and horizontal overlap (overjet) of the anterior teeth. When the mandible moves from the MIP to an edge-to-edge relationship, their path is determined by the palatal surfaces of the maxillary anterior teeth. The angle and length of the movement is determined by the incisor relationship.[1]

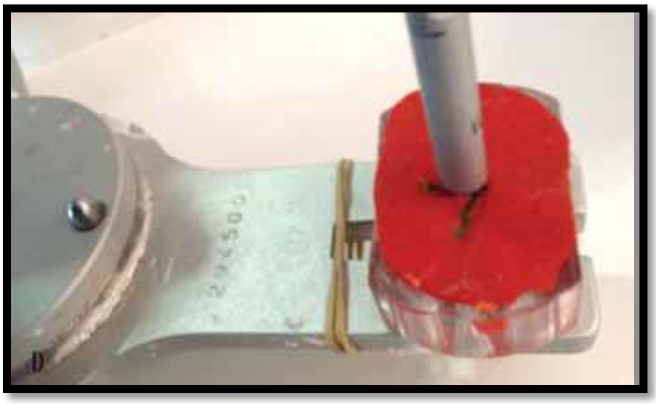


Fig 3: Incisal guidance

An unfavorable incisal guidance may tend to produce abnormal functional movements of the condyles. It may contribute to abnormal stresses and movements which are potentially pathologic. A change or modification of an unfavorable incisal guidance will have a favorable influence upon the pattern of movement of the condyles. There are right lateral, left lateral, and protrusive guide factors in the incisal guidance which have their respective influences upon eccentric functional occlusion, but we must visualize the tripod influence of these three factors (the incisal guidance and two temporomandibular joints) operating in all eccentric functional movements of the mandible.[6]

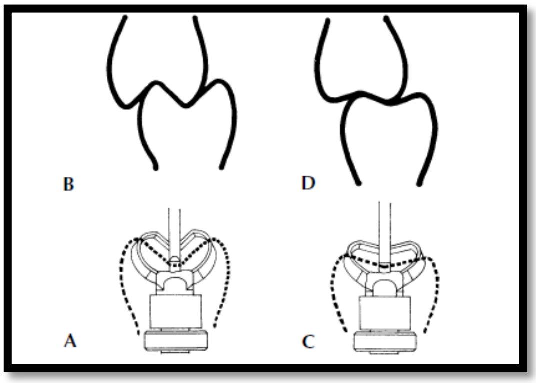


Fig. 4.—The relationship between the incisal guidance and cuspal inclination.

A, An enlarged lower tooth form (*broken line*) is superimposed upon a comparatively steep incisal guidance.The steep lateral incisal guide inclines dictate the use of the steep lateral occlusal contours of the tooth.
B, The upper and lower posterior teeth have steep lateral occlusal contours which are in harmony with the steep incisal guidance **(A)**.
C, An incisal guidance with reduced steepness of its lateral guide inclines. The enlarged posterior tooth form (*broken line*) has lateral guiding inclines in harmony with the incisal guidance.
D, The upper and lower posterior teeth have reduced steepness of the lateral inclines which are in harmony with incisal guidance **(C).**

2. PLANE OF OCCLUSION
This is defined as the average plane established by the incisal and occlusal surfaces of the teeth. Therefore, it is an imaginary plane that touches the incisal edges of anterior teeth and the cusp tips of the posterior teeth. The cusp angles of posterior teeth are influenced by the relationship between the occlusal plane and the articular guidance. Consequently, when the angle of the occlusal plane is parallel or almost parallel to the condylar guidance, the cusp height must be short and vice versa.

3.CURVE OF SPEE
This is the antero-posterior curve that touches the tips of the canine and the functional cusps of the mandibular posterior teeth. It then extends distally

through the ramus and passes through the condyle. (Figure 5)

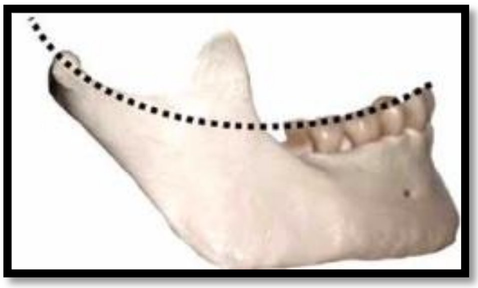


Figure 5: Curve of Spee

THE DESIGN AND LOCATION OF THE CURVE WILL SERVE TWO IMPORTANT PURPOSES

a. The long axis of each mandibular posterior tooth is aligned parallel to the arc of closure; therefore, maximum resistance to occlusal force is achieved, as most of the periodontal ligaments are involved in dissipation of imposed occlusal force (Figure 6).

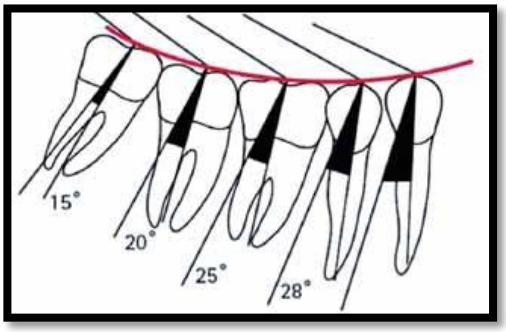


Fig 6: The long axis of each mandibular posterior tooth is aligned parallel to the arc of closure; therefore, maximum resistance to occlusal force is achieved.

b. Posterior disclusion is more easily obtained when the mandibular occlusal plane is flat or convex. Even when the incisal guidance is flat, the forward movement of the condyle on the articular eminence is at an angle that is steeper than the posterior part of the occlusal plane, which will lead to posterior disclusion.

4.CURVE OF WILSON

This is the bucco-lingual (mediolateral) curve that contacts the buccal and lingual cusp tip on each side of the arch. It results from inward inclination of the mandibular posterior teeth and outward inclination of the upper posterior teeth. The curve of Wilson is important to the masticatory system in two ways. Firstly, an optimum resistance to masticatory forces is achieved as teeth are aligned parallel to the direction of the medial pterygoid muscles, which are one of the major elevator muscles of the mandible. Secondly, the level of the lingual cusps of the mandibular teeth allows the tongue to bring food to the occlusal table and the elevated buccal cusps prevent food from going past the occlusal table. Also, the lower level of the maxillary palatal cusps prevents food from going past the occlusal table.[1](Figure 7)

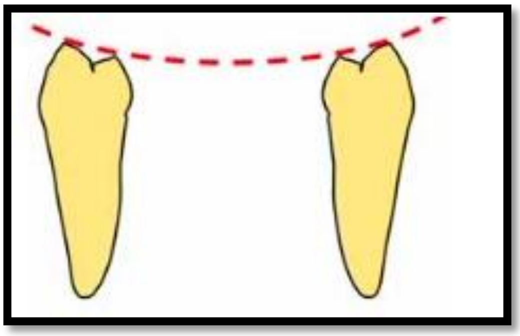


Fig 7: Curve of wilson

TYPES OF MOVEMENT

Two types of movement occur in the TMJ: rotational and translational.

ROTATIONAL MOVEMENTS

Dorland's Medical Dictionary defines rotation as "the process of turning around an axis: movement of a body about its axis."[7] In the masticatory system,

rotation occurs when the mouth opens and closes around a fixed point or axis within the condyles.
In the TMJ, rotation occurs as movement within the inferior cavity of the joint. It is thus movement between the superior surface of the condyle and the inferior surface of the articular disc.

Rotational movement of the mandible can occur in all three reference planes: horizontal, frontal (vertical), and sagittal. In each plane, it occurs around a point, called the ***axis.***

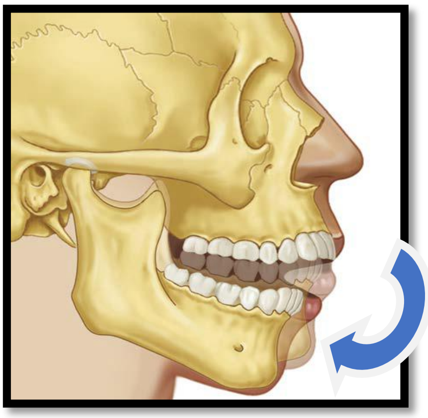
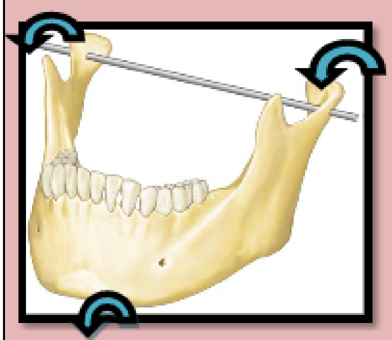
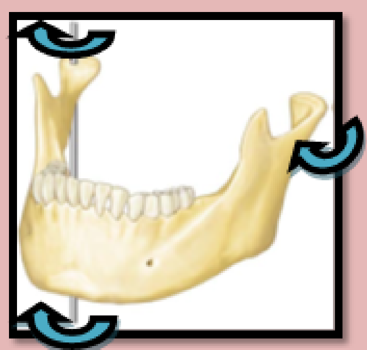
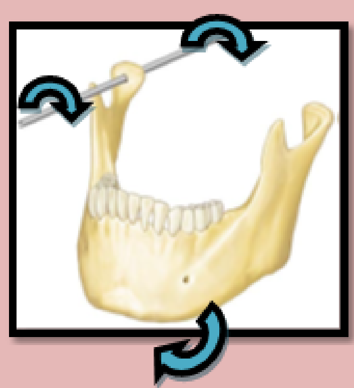


Fig. 8. Rotational Movement About a Fixed Point in the Condyle

Horizontal Axis of Rotation	Frontal (Vertical) Axis of Rotation	Sagittal Axis of Rotation
➢ It is an opening and closing motion. ➢ It is referred to as a *hinge movement*, and the horizontal axis around which it occurs is therefore referred to as the ***hinge axis***. ➢ When the condyles are in their most superior position in the articular fossae and the mouth is purely rotated open, the axis around which movement occurs is called the ***terminal hinge axis***.	➢ Mandibular movement around the frontal axis occurs when one condyle moves anteriorly out of the terminal hinge position with the vertical axis of the opposite condyle remaining in the terminal hinge position	➢ Mandibular movement around the sagittal axis occurs when one condyle moves inferiorly while the other remains in the terminal hinge position. ➢ Because the ligaments and musculature of the TMJ prevent an inferior displacement of the condyle (dislocation), this type of isolated movement does not occur naturally.
		

TRANSLATIONAL MOVEMENT

Translation can be defined as a movement in which every point of the moving object has simultaneously the same velocity and direction. In the masticatory system, it occurs when the mandible moves forward, as in protrusion. The teeth, condyles, and rami all move in the same direction and to the same degree (Figure 9).
Translation occurs within the superior cavity of the joint between the superior surface of the articular disc and the inferior surface of the articular fossa (i.e., between the disc–condyle complex and the articular fossa). During most normal movements of the mandible, both rotation and translation occur simultaneously; that is, while the

mandible is rotating around one or more of the axis, each of the axis is translating(changing its orientation in space).

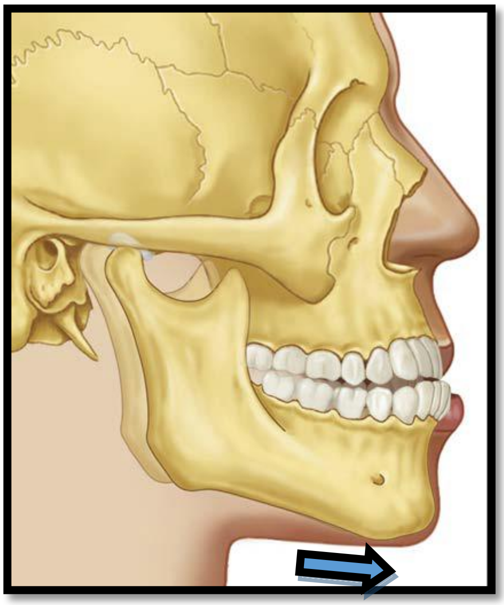


FIG. 9: Transational movement of mandible

SINGLE PLANE BORDER MOVEMENTS

Mandibular movement is limited by the ligaments and the articular surfaces of the TMJs as well as by the morphology and alignment of the teeth. When the mandible moves through the outer range of motion, reproducible describable limits result, which are called *border movements.* The border and typical functional movements of the mandible will be described for each reference plane.

SAGITTAL PLANE BORDER AND FUNCTIONAL MOVEMENTS

Mandibular motion viewed in the sagittal plane can be seen to have four distinct movement components(Figure 10):

1. Posterior opening border
2. Anterior opening border
3. Superior contact border
4. Functional.

The range of posterior and anterior opening border movements is determined, or limited, primarily by ligaments and the morphology of the TMJs. Superior contact border movements are determined by the occlusal and incisal surfaces of the teeth. Functional movements are not considered border movements since they are not determined by an outer range of motion. They are determined by the conditional responses of the neuromuscular system.

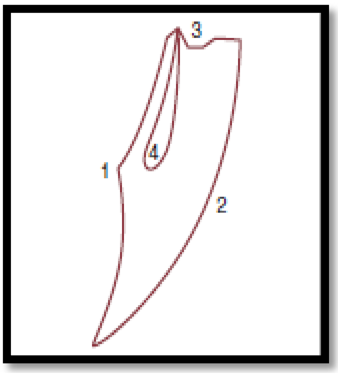


Fig 10: Border and Functional Movements in the Sagittal Plane. 1, posterior opening border; 2, anterior opening border; 3, superior contact border; 4, typical functional.

FUNCTIONAL MOVEMENTS

Functional movements occur during functional activity of the mandible. They usually take place within the border movements and therefore are considered free movements. Most functional activities require maximum intercuspation and therefore typically begin at and below the ICP. When the mandible is at rest, it is found to be located approximately 2 to 4 mm below the ICP (Figure 11). This position has been called the *clinical rest position.*

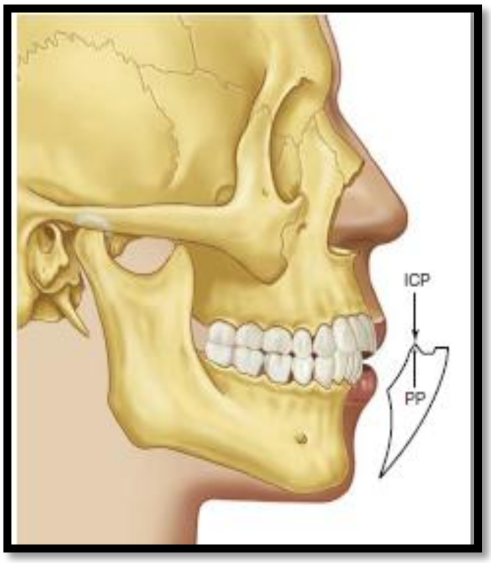


FIG. 11: The mandible in postural position (PP) is located some 2 to 4 mm below the intercuspal position (ICP).

HORIZONTAL PLANE BORDER AND FUNCTIONAL MOVEMENTS

Traditionally a device known as a Gothic arch tracer has been used to record mandibular movement in the horizontal plane. It consists of a recording plate attached to the maxillary teeth and a recording stylus attached to the mandibular teeth. As the mandible moves, the stylus generates a line on the recording plate that coincides with this movement. The border movements of the mandible in the horizontal plane can therefore be easily recorded and examined.

When mandibular movements are viewed in the **horizontal plane, a rhomboid-shaped pattern** can be seen that has four distinct movement components (Figure 12) plus a functional component:

1. Left lateral border
2. Continued left lateral border with protrusion
3. Right lateral border
4. Continued right lateral border with protrusion.

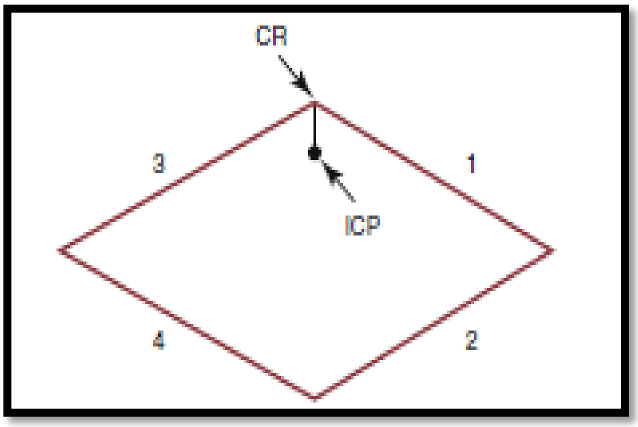


FIG. 12. Mandibular border movements in the horizontal plane. 1, left lateral; 2, continued left lateral with protrusion; 3, right lateral; 4, continued right lateral with protrusion. CR, Centric relation; ICP, intercuspal position.

FUNCTIONAL MOVEMENTS

As in the sagittal plane, functional movements in the horizontal plane most often occur near the ICP. During chewing the range of jaw movement begins some distance from the maximum ICP; but as the food is broken down into smaller particle sizes, jaw action moves closer and closer to the ICP. The exact position of the mandible during chewing is dictated by the existing occlusal configuration (Figure 13).

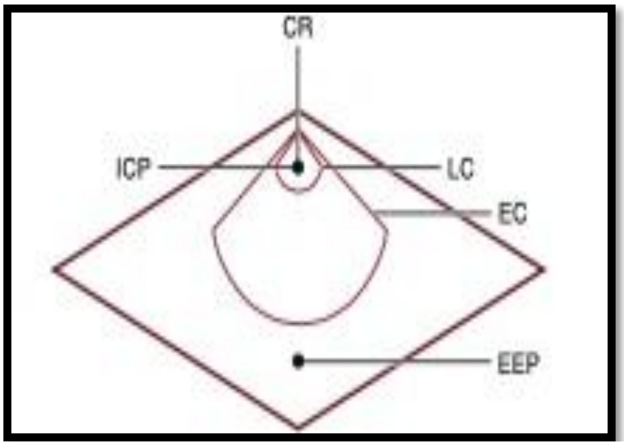


Fig. 13. Functional range within the horizontal border movements. CR, Centric relation; EC, area used in the early stages of mastication; EEP, end-to-end position of the anterior teeth; ICP, intercuspal position; LC, area used in the later stages of mastication just before swallowing occurs.

FRONTAL (VERTICAL) BORDER AND FUNCTIONAL MOVEMENTS

When mandibular motion is viewed in the frontal plane, a shield- shaped pattern can be seen that has four distinct movement components (Figure 14) along with the functional component:

1. Left lateral superior border
2. Left lateral opening border
3. Right lateral superior border
4. Right lateral opening border.

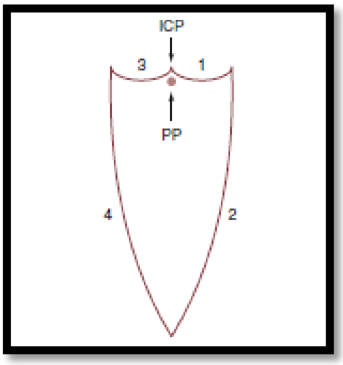


Fig. 14. Mandibular border movements in the frontal plane. 1, left lateral superior; 2, left lateral opening; 3, right lateral superior; 4, right lateral opening. ICP, Intercuspal position; PP, postural position.

FUNCTIONAL MOVEMENTS

As in the other planes, functional movements in the frontal plane begin and end at the ICP. During chewing, the mandible drops directly inferiorly until the desired opening is achieved. It then shifts to the side on which the bolus is placed and rises up. As it approaches maximum intercuspation, the bolus is broken down between the opposing teeth. In the final millimeter of closure, the mandible quickly shifts back to the ICP (Figure 15).[3]

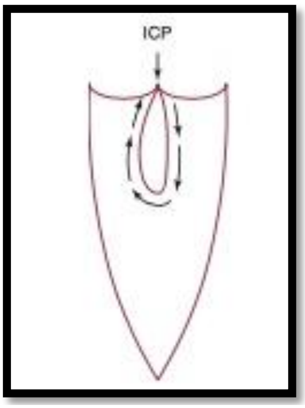


Fig. 15. Functional movement within the mandibular border movement recorded in the frontal plane. ICP, Intercuspal position.

ENVELOPE OF MOTION

By combining mandibular border movements in the three planes (sagittal, horizontal, and frontal), a three-dimensional envelope of motion can be produced that represents the maximum range of movement of the mandible. Although the envelope has this characteristic shape, differences will be found from person to person. The superior surface of the envelope is determined by tooth contacts, whereas the other borders are primarily determined by ligaments and joint anatomy that restrict or limit movement.

The limits of envelope of movement of the mandible are determined by tautness of deep capsular ligaments(Posselt 1952) .However, muscular mechanism go into action before the mechanical limitation of ligament is reached.

A given point on each condyle has a free but relatively limited mobility along its canial joint surface. This may be called the contact movement surface of the condylar point(Figure 16).[8]

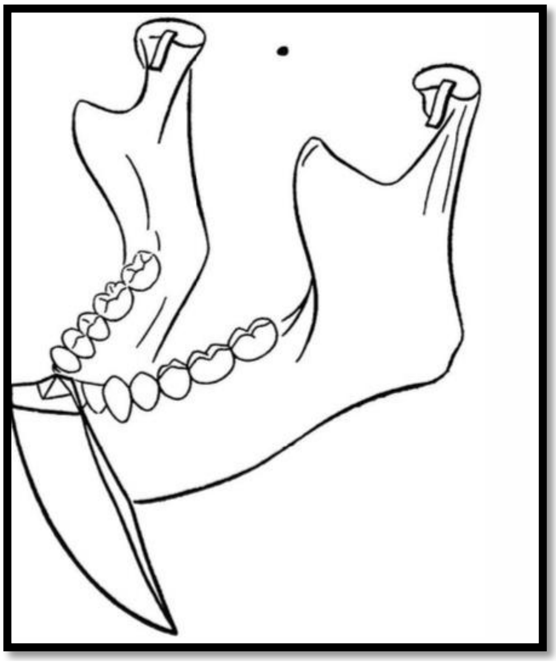


Fig. 16. Envelope of motion

LATERAL MOVEMENTS

Lateral movements are of two types namely, *lateral rotation* and *Bennett movement*.

Lateral rotation is the rotation of the mandible to any one side and the Bennett movement is the shift of the mandible towards the side of laterotrusion.

BENNETT MOVEMENT

It is defined as, "*The bodily lateral movement or lateral shift of the mandible resulting from the movements of the condyles along the mandibular fossae in lateral jaw movements*"-**GPT[9]**

Bennett movement is classified based on the timing of the shift in relation to the forward movement of the non-working condyle:

- IMMEDIATE SIDE SHIFT
- PRECURRENT SIDE SHIFT
- PROGRESSIVE SIDE SHIFT OR BENNETT SIDE SHIFT

BENNETT ANGLE

It is defined as, "*The angle formed by the sagittal plane and the path of the advancing condyle during alteral mandibular movements as viewed in the horizontal plane*" – **GPT[9].**

This is the angle formed between the path of the non-working condyle and the sagittal plane. Also called as '*horizontal condylar path*' because it is the tracing of the center of non-working condyle on the horizontal plane.

Angle formed by horizontal condylar path and sagittal plane varies between 2-44°, with a mean value of 16 degrees, called the Bennett angle. Studies have shown that variation in the direction of progressive lateral translation or Bennett angle to be about **7.5 to 12.8°.**[9]

Point to Note: To calculate the Bennett angle in a Hanau's articulator, Hanau proposed the following equation: **Bennett angle L = H / 8 + 12.**

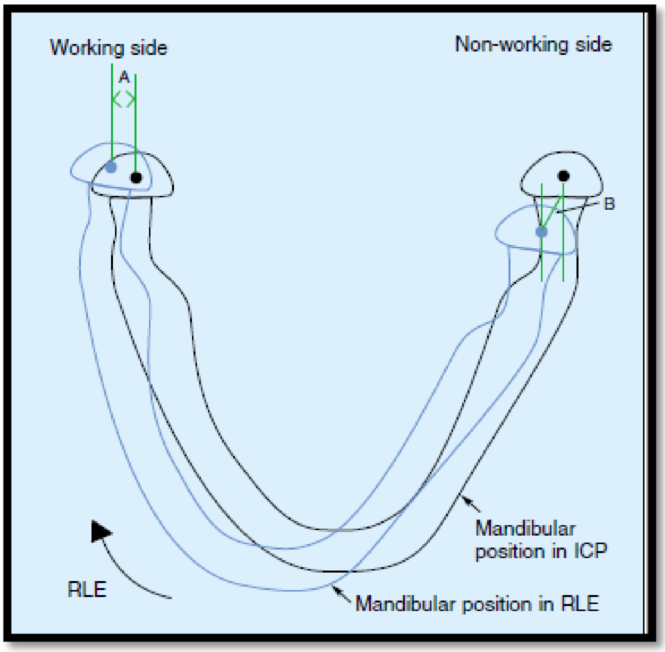


Fig.17. Right lateral excursion (RLE) viewed in the horizontal plane. A = Lateral shift or Immediate Side Shift in mm. B = Bennett Angle or Progressive Side Shift in degrees.

METHODS OF RECORDING MANDIBULAR MOVEMENTS

Several methods have been employed to measure mandibular movements. Measurement techniques include simple measurement devices, such as a millimeter ruler, to sophisticated electronic devices to record movements of the mandible using magnets or photodiode sensors. Many of them are based on the use of recording instruments that usually employ sensors fixed on the mandible,[10] such as ultrasound,[11] accelerometers,[12] electromagnetic fields,[13] videofluoroscopy,[14] and optoelectronic devices. Other methods include graphic tracings,[15] imaging (lateral radiographs),[16] or electromagnetic transducers cemented on anterior teeth.

- Methods using Mechanical Devices
- Photographic Methods
- Roentgenographic Methods
- Electronic and Telemetric Methods
- Magnetometry
- Opto-electronic Methods
- The Mandibular Kinesiograph
- Pantographs
- Cadiax Compact
- Computerized Analysis of Mandibular Movement
- Computer-monitored Radionuclide Tracking[17]

CONCLUSION

The study of jaw movements or mandibular kinematics has important applications in many fields of clinical dentistry and provides a basis for modern concepts of dental occlusion. For replacement of teeth and restoring function, a prosthodontist must have a knowledge of the mandibular movements as it aids in selection and programming of articulators, understanding occlusion, fabricating dental restorations, and arranging artificial teeth.

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