Introduction

One of the goals of restorative treatment is maintenance and/or re-establishment 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 temporomandibular joints (TMJs). All members of the masticatory system should work in harmony and accommodate the changes in occlusal morphology of the finished restoration well. Therefore, dentists must have a sound knowledge of dental occlusion and masticatory systems. This article provides clarification of the basic principles of dental occlusion, as well as an overview of this subject area, which is vital for every dental student and dentist. To avoid confusion, the terms and definitions of the Glossary of Prosthodontics are used.

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 (Figure 1). 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. Nonetheless, it has been reported that the superior head of the lateral pterygoid muscle is attached to the anterior medial portion of the capsule, with varying degrees of attachment to the lateral aspect of the capsule. Parts of the superior head of the lateral pterygoid muscle were also reported to attach to the mandibular condyle. However, no direct insertion of
the superior head of the lateral pterygoid muscle into the disc was found. 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.

**Types of mandibular movements**

The mandible can perform two types of movements: translational and rotational. In general, translational movements occur when all parts of a body move in the same direction at the same speed. In the TMJ, the condyle and disc move together along the articular eminence as in the mandibular protrusive movements. This movement takes place in the upper joint compartment. Rotational movement occurs when the condyle rotates around an imaginary axis. These rotational movements occur in the lower joint compartment. Rotational mandibular movements are described around three imaginary axes: horizontal (also known as the terminal hinge axis; THA); vertical; and, sagittal. The THA is an imaginary axis, which passes through the two condyles. In centric relation (CR), the mandible can only execute hinge opening and closing. These rotational movements occur in the sagittal plane and in the range of 20-25mm when measured between the upper and lower incisors. The vertical axis passes through the working condyle during lateral excursion of the mandible. The sagittal axis is an anteroposterior axis, which passes through the working condyle during the lateral excursion of the mandible. In this case the non-working condyle is seen rotating downwards and medially.

**Working and non-working side**

During mandibular lateral excursions, the side of the mouth to which the mandible has moved is known as the working side, while the side of the mouth from which the mandible has moved away is known as the non-working side. The condyle of the working side is denoted as the working or rotating condyle, and the condyle of the non-working side is called a non-working or orbiting condyle. While the working condyle rotates around the vertical axis during mandibular lateral excursion, it may also move laterally as well as backwards, upwards and downwards (Figure 2). However, the translatory part of lateral movement of the mandible in which the non-working condyle moves is straight and medial as it leaves the CR. This movement is known as an immediate side shift. This side shift describes a lateral translation of the mandible towards the working side in which the non-working condyle moves medially before its forward movement occurs. This was previously called the Bennett movement. It is important to highlight that this immediate side shift represents the lateral movement of the whole mandible sideways towards the working side, and it precedes the rotational movement of the working condyle. The amount of the immediate side shift may differ among patients and bilaterally within patients. There is also another side shift called a progressive side shift. This represents a translatory portion of mandibular movement as viewed in a specific body plane and occurs at a rate or amount that is directly proportional to the forward movement of the non-working condyle. Both movements (immediate and progressive) represent the lateral translation movement of the mandible and have an effect on the occlusal morphology of teeth, and consequently on mandibular movements. It is important to mention that the immediate and progressive side shifts describe the lateral translation of the mandible towards the working side in relation to the movement of the non-working condyle. Furthermore, both movements have a role to play in mandibular lateral excursive movements.

**Mandibular positions**

Two mandibular positions are important from a restorative point of view, i.e., maximum intercuspal position (MIP) and CR. MIP is also known as maximal intercuspation, intercuspal position, habitual occlusion, habitual centric, centric occlusion and acquired centric. CR is also called centric maxillomandibular relationship (CMMR) and retruded axis position.

**Maximum intercuspal position**

MIP is defined as the complete intercuspation of the opposing teeth independent of condylar position in the glenoid fossa, also referred to as the best fit of the teeth regardless of the condylar position. In MIP the condyle-disc assembly is usually anterior and inferior and/or medial or lateral, or a
combination of the above, compared to their position in CR. The average
distance between CR and MIP in 90% of the population is 0.5-2mm.20,21 In this
position, a maximum occlusal force can be applied and the maximum number
of occlusal contacts is found. Therefore, it is the position of maximum stability
of the mandible. MIP provides a steady position for the mandible during
swallowing and severe physical exertion.6,16,22 In a subject with normal
physiological occlusion the MIP is a precise, readily identifiable position when
an adequate number of posterior teeth is present. It is the most commonly used
reference position in the clinic.17,18,23

Centric relation
CR is a position of the condyles when they articulate with the thinnest avascular
portion of their respective discs and the condyle-disc assembly is in the
anterior-superior position against the articular eminences.5,8 This position is
independent of tooth contact. The CR is actually not a mandibular position but
an axis around which the mandible can rotate. It is restricted to a purely
rotational movement about the THA.6,19 The CR is clinically identifiable,
recordable and reproducible in patients with no pain or derangement in the
TMJ.6,20 The position of the condyle in CR is usually taken as a starting point
when the MIP is not satisfactory, or when occlusal rehabilitation is needed
(Figures 3 and 4) and is also used in edentulous patients when complete
dentures are planned.

In order to record the CR clinically, several methods are used. These include
bimanual mandibular manipulation with or without a jig, chin point guidance
with or without a jig, and Gothic arch tracing. The bimanual manipulation
method has been found to be more consistent than the other two methods.14
The CR and MIP of the mandible on the mandibular border movements in the
sagittal plane are shown in Figure 3.

Border movements of the mandible (Figures 3, 5 and 6)
Extremes or border movements of the mandible are described as an envelope of
motion or Posselt’s envelope of motion.17,20,24 These movements can be
demonstrated by tracing the movements of the lower incisors when viewed in
the sagittal, frontal or horizontal plane (Figure 5).
The cranial extent of Posselt’s envelope of motion is controlled by the teeth, while the mandibular movements along all other borders and within the envelope are mainly controlled by the TMJ. The border movements can be described as follows:

1. The mandible initially opens with a hinge movement about the THA, with the condyles in the CR. The red arc in Figure 5 represents this rotational movement. This creates an incisal separation of 20-25mm.

2. If the mandible is guided to move along the arc of rotation in the CR, it usually slides on the upper tooth/teeth, which then bring the mandible into the MIP. The tooth contact in this position is known as first tooth contact (FTC) or slide or retruded contact (RC) (Figures 5 and 6). The FTC guides the mandible along the deflective path (black slope in Figures 3 and 5) into the MIP. This movement usually has both vertical and horizontal components, and is typically less than 1mm in the anteroposterior direction. Clinically, this contact may be identified when the patient is relaxed and the clinician guides the mandible into the CR and then the patient is asked to close. It is also important to mention that the patient usually avoids the FTC and closes the mandible straight to the MIP along the habitual path (yellow arc in Figures 3 and 5).

3. The upper limit of the envelope of motion consists of edge-to-edge relationship, incisal guidance, MIP and FTC.

4. On further opening, the condyles translate downwards and forwards along the articular eminences to a point of maximum opening. This movement represents the mid-sagittal depression during the clinical examination. The transitional arc is represented by a dashed line in Figures 3 and 5.

5. When the mandible moves from the maximum mouth opening in the upward and protrusive direction (blue arc in Figure 5) until the lower teeth make contact with the upper teeth, this arc of movement is known as a protrusive arc. It represents the extreme movement of the mandible in a protrusive direction.

**Determinants of occlusion**

Occlusion and mandibular movements are controlled by three determinants (factors): the TMJ, known as the posterior determinant; the teeth, known as the anterior determinant; and, the overall neuro-masticatory system (Table 1). 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.

**A. 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. For instance, the shape and angle of the articular eminence of the glenoid fossa affect the movement of the mandible and teeth by the path that the condyles must travel when the mandible moves. The range of angulation of articular eminence at the midpoint inclined plane is between 17° and 77°. 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. Only a few examples of these factors are discussed in this article:

1. Condylar inclination denotes the angle at which the condyle descends along the articular eminences in the sagittal plane. For example, the greater the angle of the articular eminence, the greater the steepness of the cuspal angle and the deeper the fossa (Figure 7). 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. Therefore, the prospective restoration with a steep cuspal angle is permissible as the teeth are less likely to clash.
2. Mandibular side shift and the steepness of the cuspal angle
   The mandible may bodily shift sideways during its lateral movements as mentioned earlier. If there is a bodily shift, there will be a downwards, forwards or medial component. During lateral excursion movement, the non-working condyle moves downward, inward and forward. The inward movement of the non-working condyle is affected by two anatomical factors: (1) the morphology of the medial wall of glenoid fossa and its proximity to the medial pole of the non-working condyle; and, (2) the inner horizontal part of the temporomandibular ligament that is attached to the lateral pole of the working condyle. These two factors dictate if there will be a lateral mandibular side shift (immediate or progressive).12
   For example, if the temporo-mandibular ligament attached to the working condyle is tight and the medial wall of the glenoid fossa is close to the medial pole of the non-working condyle, no immediate side shift will occur and therefore a steep cuspal angle is allowed (Figure 8B). However, if the temporomandibular ligament is loose and a space exists between the non-working condyle and the medial wall of the glenoid fossa, an immediate side shift will occur (Figure 8A). When teeth are restored, the presence of an immediate side shift allows a lesser steepness of the cuspal angle, shorter cusps and a shallower fossa, and also requires grooves to let the opposing cusp escape. A progressive side shift allows for a steeper cuspal angle, greater cusp height and consequently a deeper fossa (Figure 8B).
   It is important to mention that both the direction and timing of the side shift also affect the steepness of the cuspal angles. Additional to its rotating movement, the working condyle can also move superiorly, inferiorly, posteriorly and anteriorly. All these movements influence the occlusal morphology of the teeth.
   Also, downward movements of the non-working condyle in relation to the horizontal plane affect the occlusal morphology of posterior teeth, as the greater the angle of the path, the greater the steepness of the cuspal angles and the deeper the fossa.

B. 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 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. It is important to note that the anterior determinant represents both anterior and posterior teeth and their effect on the mandibular movements, and not only anterior teeth. Examples of elements of the anterior determinant:
   1. Incisal guidance (vertical and horizontal overlap of anterior teeth).
   2. Occlusal plane.
   3. Curve of Spee.

1. Incisal guidance (Figure 8)
   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 (Figures 3, 5 and 9). The angle and length of the movement is determined by the incisor relationship. For instance, in Class II division 2 occlusions, the movement is almost vertical, as the lower incisors are locked palatal to the upper incisors and cannot easily slide forward (Figure 9B). Consequently, when the vertical overlap is increased the cusps of the posterior teeth can be longer and vice versa. However, when horizontal overlap is considered, the greater this overlap the shorter the cusp height will be in order to avoid cusp collision. On the other hand, when this horizontal overlap is reduced, the cusp height increases.
   The anterior teeth are suitable to guide the mandible in protrusive and lateral excursions. Firstly, the anterior teeth (including canines) usually have a vertical overlap, which allows them to disengage the posterior teeth when the mandible moves from the MIP. Secondly, the heights of cusps of the posterior teeth decrease posteriorly, which also facilitates their disengagement when the mandible moves from the MIP. Thirdly, the mandible is a type III lever (like a nut cracker); hence, the occlusal force on these teeth will be less than that imposed on the posterior teeth. Fourthly, the proprioceptors’ threshold and reflex reaction reduces the load on anterior teeth.6,14 Then, anterior teeth are suitable to protect the posterior teeth during excursion movements of the mandible without a negative effect being imposed on them.
   The incisal guidance is of paramount importance for function, aesthetics and phonetics. Therefore, when the incisal guidance is satisfactory, it should be
maintained whenever possible, or should be copied in the new restoration when
the involved anterior teeth are being restored. This can be achieved by
customising the incisal guidance and copying the palatal surface of these teeth
in an impression from which the technician can transfer the palatal surface of
the teeth to the restorations, or by using a custom-made incisal guidance (Figures 9D and 9E).

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 (Figures 10 and 11)
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. 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 11).
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.

The curvature of the curve of Spee can be described according to the length of
the radius of the curve. The length of the radius of this curve has an effect on
the occlusal plane and on the cusp heights of posterior teeth. When the radius
of the curve is long (less concave/less acute), the occlusal plane is flatter than
when the radius is short (more concave/more acute). The amount of
separation (disclusion) between the mandibular and maxillary posterior teeth is
dependent on the length of the radius of the curve of Spee such as when the
radius is short, the separation is greater and the posterior cuspal angles are
steeper than when the radius is longer.

The curve of Spee may be pathologically altered by rotation, tipping and over-
erection of teeth. For example, an over-erupted tooth, after extraction of
opposing tooth/teeth, may lead to occlusal interferences and disturbance in
the occlusal plane and curve of Spee (Figure 12). Corrections of such
disruption may be required before restorative interventions can be carried out. The corrections include enamelo-plasty, when a minimum correction is required, or orthodontic tooth intrusion, elective endodontic treatment, or extraction of a causative tooth/teeth in severe cases.

4. Curve of Wilson (Figure 13)
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.25 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.25

A disturbance in the curve of Wilson may create an occlusal interference. For example, when a maxillary palatal cusp is tilted so it becomes below the curve of Wilson, a non-working side interference may be created and its correction is necessary before restorative treatment can be carried out, as displayed in Figure 14.

Canine guidance
The Glossary of Prosthodontic Terms5 defines canine guidance as a form of mutually protected occlusion in which the vertical and horizontal overlap of the canine teeth disengage the posterior teeth in the excursive movements of the mandible. Accordingly, when the mandible moves to one side, the overlap of canines results in separation (disclusion) of posterior teeth on the working side.21,27,28 The mandible is guided by the canines during its lateral excursions with posterior teeth disclusion (Figure 15). In lateral mandibular excursions, the vertical and horizontal overlap relationships of the canines should be enough to disclude all other teeth. Canine guidance is more commonly seen in young patients whose canines are not worn.29 It may also be created by adding restorative material (such as composite) when a posterior fixed prosthesis or implant-retained fixed prosthesis is planned in order to protect it. Canine teeth are suitable to guide the mandible during its excursive movement for many reasons, as previously mentioned. Furthermore, canines have a favourable root anatomy and a lower crown–root ratio. They are also supported by sense and compact bone, which tolerate occlusal forces better than cancellous bone. In addition to this, they have a strategic position in the jaws.

Group function
Group function is defined as multiple contact relations between the maxillary and mandibular teeth in lateral movements on the working side whereby
simultaneous contact on several teeth acts as a group to distribute occlusal forces.\textsuperscript{5} When the mandible moves to one side, two or more pairs of opposing teeth guide the mandible (Figure 16).\textsuperscript{21,27,28,30} Ideally, contacts should be between canines, premolars and the mesiobuccal cusp of the first molar. The group function occlusion can be seen in patients whose canines were worn away or are missing, thus allowing the posterior teeth to come in contact during lateral movements of the mandible.\textsuperscript{21,27,28,30} It may also be found in Class III malocclusion when the anterior teeth are in an edge-to-edge position, or have a reverse horizontal overlap.

Group function occlusion may be planned when the anterior teeth have lost a considerable amount of their periodontal support. It is often necessary to allow the posterior teeth to share the occlusal forces and to guide the mandible with the anterior teeth. The advantage of group function occlusion is that the occlusal forces are shared among several teeth. However, the occlusal forces are not along the long axis of the involved teeth and, therefore, only part of the periodontal ligaments are involved in dissipation of occlusal forces. Group function is indicated in cases of anterior open bite, when the alignment of the anterior teeth (canines) does not allow disclusion of posterior teeth on the working and non-working side, as well as when the crown-root ratio is significantly increased, as in patients with clinical attachment loss. Furthermore, it is indicated in Class I malocclusion, in which the horizontal overlap (overjet) increases to a degree in which canine guidance cannot be obtained. Therefore, these factors are to be considered when the choice between canine and group function is being made.

It is also important to remember that another type of occlusion, known as balanced occlusion, is described in the literature. It indicates simultaneous occlusal contacts of the upper and lower teeth on the right and left side of the jaw, in the anterior and posterior regions when the mandible is in MIP, and during excursive movements. It is a prosthetic term used to stabilise the denture during function. It is not applicable for normal dentitions and therefore should be avoided.

**Recording of factors that affect occlusal morphology**

Several materials are used in registration of the static and dynamic occlusion. To be suitable to record the occlusion precisely, they should not interfere with the mandibular movement. They should be accurate enough to record sufficient details that enable the cast to be oriented correctly. They also need to be sufficiently rigid not to become distorted during handling and the mounting procedure. The most commonly used materials are wax or silicone impression materials. The recording materials are not required when the MIP is satisfactory. Witness marks are used to enable the clinician/technician to relate the lower cast to the upper cast in a similar relationship to that of the mouth. It should be understood that the casts do not represent the actual picture of the mouth, as some variations do exist. The teeth may be displaced when the patient closes his/her mouth as periodontal ligaments are resilient and easily disturbed. This phenomenon is not present in casts. However, when the MIP is not reproducible by the best fit, interocclusal recording materials such as wax, silicone or acrylic may be used to relate the casts in the MIP when a sufficient number of teeth are present. This makes the identification of the MIP possible. Incisal guidance can be customised and used in the construction of the palatal surfaces of the maxillary anterior teeth when they are involved in the preparation of the prospective restorations (Figures 9D and 9E). Table 2 displays the static and dynamic occlusal factors that can be recorded clinically and transferred to the articulators.

**Conclusion**

Basic knowledge of occlusion is needed for a better dental treatment outcome. Therefore, clinical examination, which consists of examination of the TMJ, teeth and soft tissue as well as the periodontium, should be carried out before commencement of dental treatment. Furthermore, several factors that influence mandibular movements during function should be considered, as they may be negatively changed and consequently lead to unintended outcomes.

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