Introduction
There is a general belief among dentists that occlusion plays a significant role in para-functional activities, which may lead to temporo-mandibular disorder (TMD). Subjects with a history of TMD showed more clinical signs when an artificial occlusal interference was introduced than subjects without a previous history of such a disorder. However, the aetiology of TMD is multifactorial in nature and occlusion may be just one of these factors. Nevertheless, there is a weak association between occlusion and TMD, although there is no evidence to support occlusal adjustment as a treatment for TMD, bruxism or headaches, as previously suggested. Yet, it is important to realise that patients’ response to an occlusal interference and a lack of harmony between parts of the stomato-gnathic system may vary. Therefore, it is important that the aim of any restorative treatment is to fulfill the requirements that reduce any possible unwanted effects that may arise by occlusal interference. Thus, minimum to no effort from the masticatory system to accommodate this abnormality is required. Also, a properly designed restoration that maintains a good occlusal relationship between the opposing teeth will result in correct form, function and comfort. This improves the restoration success and reduces its failure. The aim of this article is to provide an overview of the type of occlusal contacts in the maximum intercuspal position (MIP), and the occlusal interferences and methods of their marking and detection. It also provides practical points that should be considered when restorative treatment is carried out in order to prevent restoration failures.

Supporting and non-supporting cusps
Cusps of posterior teeth can be classified into supporting and non-supporting cusps. The supporting cusps are mandibular buccal and maxillary palatal cusps when the posterior teeth are normally related (i.e., no cross-bite or reverse horizontal overlap). The non-supporting cusps are the mandibular lingual and the maxillary buccal cusps. While the supporting cusps are rounded and blunt, the non-supporting cusps are well shaped and pointed. The supporting cusps maintain vertical occlusal dimension and play major roles in mastication. The tips of the supporting cusps are usually located close to the centre of the tooth; therefore, the occlusal forces are directed along the long axis of the tooth and lateral stresses are minimised when the teeth are in the MIP. The non-supporting cusps provide the vertical and horizontal overlap between the posterior teeth that minimises tissue impingement (tongue and cheek biting), and they guide the mandible during mastication. They also maintain the food bolus on the occlusal table. Each cusp has an inner and outer aspect (surface), which are made up of incline planes. The inner aspect extends from the cusp tips to the central fossa, while the outer aspect extends from the cusp tips to the height of the contour on the labial and lingual surfaces of the posterior teeth.

Abstract: This second part of the two-part article discusses different types of occlusal contacts and their interferences. It also provides a practical guide to what is required to optimise the restorative treatment outcome. Occlusion and its effect on dental implants are also presented. Clinical relevance: Restorative treatment outcome is highly dependent on the occlusion of the restoration when the treatment is complete.
The contact between upper and lower teeth

The area of occlusal contact between unworn opposing teeth is small. The level of friction is low as a consequence, and the space for the escape way to be reduced. The whole outer aspect of the supporting cusp may eventually occlude with the inner aspect of the non-supporting cusp. The occlusal contacts in the MIP and the position of the mandible in the MIP should be stable so that occlusal force does not cause adverse effects. However, the number of occlusal contacts per tooth is low. A lower number of occlusal contacts was found when light occlusal pressure was applied than when a heavier pressure was applied. This occlusal area of contact was found to increase with increasing of the occlusal pressure.

Types of occlusal contact in the MIP

In the MIP, the mandibular teeth make contact with their opposing maxillary teeth and a maximum number of occlusal contacts was found in this position. Preferably, the occlusal contacts should lead to stability of the involved teeth and direct the occlusal forces along the long axes of these teeth. The types of occlusal contacts that are found in normal occlusion, or applied in occlusal reconstruction treatments, may be classified as follows:

A. Supporting cusp against a flat surface

The supporting cusp tip contacts a flat surface of the opposing occlusal table such as the base of the fossa or the occlusal embrasure. This is the ideal relationship as the occlusal forces are directed perpendicular to these surfaces. This type of contact is a therapeutic objective recommended for restorative treatment. With this type of contact, there is little potential to develop a horizontal component of force because of the absence of inclined plane effects. Also, the occlusal force is usually directed along and not outside the long axis of the involved teeth (see below). However, this type of occlusal contact may suffer mechanical disadvantages, as will be seen later. The supporting cusp tip occlusal contacts may be further subdivided into a single cusp tip to fossa or a twin cusp contact (Figure 1).

1. Single cusp tip to fossa or marginal ridge contact

This is found when a cusp tip of a supporting cusp of a mandibular or maxillary tooth occludes with a fossa or a marginal ridge of an opposing tooth. It is important to mention that this arrangement, when analysed mechanically, may favour tilting the cusp-contact tooth facially or lingually because the relevant tooth is loaded outside its long axis (Figure 1A).

2. Twin cusp stability

This exists when cusp tips of both mandibular and maxillary supporting cusps occlude with the fossa or the marginal ridge of opposing teeth (Figure 1B). Mechanically, this may be a more favourable type than the single cusp tip contact.

B. Occlusal contacts on inclined planes

Occlusal contacts on inclined planes are found when the supporting cusp makes contact with an opposing inclined surface. In unworn dentitions, a small area of the outer aspect of the supporting cusp contacts with a small area of the inner aspects of the opposing non-supporting cusp. Hence, the supporting cusp tip will not make contact with the bottom of the fossa or marginal ridge of the opposing tooth. The posterior tooth contacts on the incline plane may be type A, B or C, or a combination of these types of contacts (Figure 2).

A-type occlusal contact indicates the contact between the outer incline of the lower supporting cusp and the inner incline of the upper guiding cusp (Figure 2).

B-type occlusal contact is when the occlusal contact exists between the inner incline of the mandibular and maxillary supporting cusps (Figure 2).

C-type occlusal contact is the contact between the inner incline of the mandibular guiding cusp and the outer incline of the maxillary supporting cusp (Figure 2).

In the theoretical mechanical sense, the most favourable contacts on an inclined plane are either: two contacts on opposing planes such as A-B and B-C, or, three-point contact such as A-B-C. For instance, A-B and B-C are more stable occlusal contacts than if only A and C are in contact without B (Figure 3).
3). In this case, the lower tooth will tip in the lingual direction and the upper tooth will tip in the buccal direction (Figures 3 and 4). This will result in working and non-working interferences (see below).

Occlusal contacts are also described as a tripodal contact, when three contacts (A, B, and C) present together on the same pair of teeth, or when the supporting cusp has three points of contact around its tip. This results in a stable occlusion.

Detecting and marking of occlusal contacts

The occlusal contacts can be clinically marked basically by two methods: use of articulating papers; or, waxes and impression materials. Feeler gauges such as shim stock (8-12μm) are used to verify the presence of the occlusal contact when they are detected with the articulating papers, waxes or impression materials. T-scans are also used for recording the time and duration of contacts, but mainly in the field of research.

Articulating papers

The articulating paper does not allow contact between the occlusal surfaces of the opposing teeth as a result of the presence of the strip, such as paper, which is painted with the colouring material. Occlusal pressure results in the coloured material being deposited on the occlusal surface near or at the actual place where tooth surface to tooth surface contact would otherwise occur. The reliability of the marking is related to the thickness and properties of the articulating paper.

When an articulating paper of about 40μm is used to mark occlusal contacts, only halo marks should be considered as actual occlusal contacts (Figure 5). However, a smudge marking does not represent an actual occlusal contact but indicates that the teeth are close to being in contact. The smudge markings indicate that opposing occlusal surfaces are close to a distance that is less than the thickness of the used articulating paper. Therefore, it is important to use a thin articulating paper and the existence of occlusal contacts is verified by the use of shim stock. Thick articulating paper may lead to an inaccurate/false positive and often larger points of occlusal contacts. Furthermore, articulating papers cannot easily mark contact on glazed porcelain or polished gold surfaces, or when the tooth surface is wet, which will result in false negative markings and recordings. However, one of the advantages of double-sided articulating paper is that the occlusal contacts in opposing arches can be recorded.

Waxes and impression materials

This method has the characteristic that actual contact between the opposing occlusal surfaces occurs in the process of identifying the contact. The materials are placed, as a covering layer of wax, carbon, coloured chalk, or aerosol, on the mandibular or maxillary occlusal surfaces. Cusps of the opposing occlusal surfaces penetrate the deposited material at the points of occlusal contact. Perforations of the marking media indicate actual tooth contacts. In this method, actual occlusal contacts can be seen when the marking media is displaced and the opposing tooth surfaces touch each other. The major disadvantage is that the contacts are disclosed on only one antagonist at a time. The process must be repeated to find the contacting points on the opposing occlusal table. Hence, the clinical procedure to identify the paired contacts is lengthy and tiresome. Besides indicating the contact spot, i.e., the perforations, some clinicians use trans-illumination of the indented material to identify points of ‘near contact’ as reflected by thinning of the material, which actually indicates close contact but not a real occlusal contact. This is a very subjective and variable procedure that requires a precise and repeatable method of laying the material on the occlusal surface prior to testing for
contacts (Figure 6). It is important to mention that the marking material may stick to the tooth surface and tear, which gives wider occlusal contact than its actual size. Also, no occlusal marks are left on the surface, which requires the clinician to re-mark them, after which the marking medium is removed. This method is more useful when used on study casts or in the laboratory. For these reasons this method is used only when the use of articulating paper is not satisfactory, as when moisture control is not achievable.

**Marking of occlusal contacts using articulating paper**

The teeth need to be dry and the patient’s dynamic occlusion should be marked first by asking the patient to tap his/her teeth, and asking them to make different excursion movements to mark the dynamic occlusion. An articulating paper of a different colour is then used to mark the patient’s static occlusal contacts (MIP) by asking the patient to tap his/her teeth together into a normal bite (MIP). This ‘dynamic-static’ order will produce a clear representation of the occlusion. It is much more reliable than the ‘static-dynamic’ examination order, which tends to rub off the static occlusion markings during the excursive movements. Figure 7 shows the armamentarium used in clinical marking of occlusal contacts.

**Occlusal interference**

Occlusal interferences are defined as undesirable occlusal contacts that prevent smooth movements of the mandible. However, according to the Glossary of Prosthodontic Terms, an occlusal interference is any tooth contact that inhibits the remaining occluding surfaces from achieving stable and harmonious contacts. The occlusal interferences may be considered as a potential damage in some subjects; others may adapt to them. As previously mentioned, they change the lever system of the mandible. It is important to mention that contact on the non-working side may exist without correlation between this type of occlusal contact and mandibular dysfunction. However, their adjustment before any restorative work is important. Furthermore, distinction between an occlusal interface and an occlusal contact that does not hinder smooth movement of the mandible, should be made clear. As an example, a non-working side occlusal contact may be present during lateral mandibular guiding excursion, but it is not necessarily denoted as an interference. In this case, its correction is not mandatory. However, occlusal examination is important to identify occlusal interferences and their correction when indicated. For instance, when a restoration such as a single crown or a fixed prosthesis is planned, it is important to remove any occlusal interference if the tooth/teeth will be part of the prospective restoration. This correction should be carried out even before any tooth preparation takes place. This allows the patient to get used to the new guided mandibular movement, and the required occlusal clearance is maintained when the tooth is prepared to receive the planned restoration. Therefore, the restoration and the tooth will be protected from any damage that may occur due to the presence of such interference. It is also important to avoid incorporation of occlusal interference as a result of a new restoration by a careful clinical and laboratory examination before and after cementation of the restoration. The occlusal interferences may be classified as follows:

1. **Centric interference**

Centric interference indicates the first tooth contact (FTC) on the arc of rotation on the envelope of mandibular movement when the MIP does not coincide with the centric reaction (CR). It is also known as retracted contact. It usually occurs between the mesial incline of an upper tooth and the distal incline of a lower tooth (Figure 8). It may also occur between the inner and outer inclines of opposing teeth, which leads to deviation of the mandible to
the right or left side. When it presents, the mandible usually avoids this contact by closing directly into the MIP. Clinically, this interference 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. The mandible will slide into the MIP. As an example, this type of occlusal interference may be adjusted if the involved tooth is to be prepared and included in a restoration or when a reorganised occlusal scheme is to be implemented. The centric interference may be identified clinically and recorded using an inter-occlusal record, which is used to relate the mandibular study cast to the maxillary one. Then, the interference can be verified and corrected if indicated.

2. Working-side interference
This occurs on the side towards which the mandible is moving. When such contact occurs, it hinders smooth harmonised mandibular movements and separates the other teeth of the working side (Figure 9). As an example, this type of occlusal interference may occur between the outer inclines of the maxillary supporting cusps and the inner inclines of the mandibular guiding cusps.

3. Non-working side interference
Non-working side interference is an undesirable contact of the opposing occlusal surfaces on the non-working side. It usually occurs between the inner incline of the supporting cusps of opposing teeth (Figure 10) and discludes other teeth. The involved tooth/teeth act as pivot and shift the fulcrum from the temporomandibular joint (TMJ), lifting the working-side teeth out of contact. Mechanically, the non-working side interference has a negative effect on the stability of the TMJs and on their loading. In the presence of such interference, the lever system of the mandible changes and the non-working interference becomes the fulcrum for the mandible under the effect of the masticatory muscles. The TMJ may distract and lose its stability as the mandible pivots around the non-working interference/contact. Also, the relevant teeth are overloaded, as occlusal forces are imposed on these teeth and outside their long axes. Therefore, it has been suggested that this type of occlusal interference may have the potential to damage the TMJ and dental structures as a result of the amount and direction of the generated forces. However, the evidence for this suggestion is poor. Normally, occlusal contacts trigger proprioceptors and nociceptors in the periodontal ligaments, which have inhibitory effects and, consequently, inhibit contractions of the masticatory muscles.

4. Protrusive interference
Protrusive interference occurs between the mesial inclines of the mandibular posterior teeth and the distal inclines of the maxillary posterior teeth during mandibular protrusive movement (Figure 11). It causes separation (disclusion) of the anterior teeth during this movement. It may also cause locking of the mandible. During protrusive movements, all forces of the elevator muscles are imposed on the anterior teeth and TMJ. This results in a high horizontal component against the upper anterior teeth as the contact is along their palatal surface. To protect the anterior teeth from being overloaded, a well-designed sensor system can shut most of the elevator muscle activity at a precise moment of complete posterior separation. However, this mechanism is negatively affected when the protrusive interference is present, as this interference activates the elevator muscles and leads to their hyper-contraction.

Types of occlusal schemes used when restorative treatments are carried out
The first step before any restorative treatment is carried out, is to decide on which occlusal scheme to use. In general, there are two approaches: conformative; and, reorganised. Conformative approach
This approach is indicated when the patient’s MIP will be used. It is the most commonly used treatment option when the MIP is satisfactory. It is recommended when a small restoration or bridge will be constructed or when there is no need to restore the entire occlusion at once. It is also advised when unprepared teeth provide the MIP...
Check the MIP before commencement of cavity or tooth preparation.

Adjust occlusal interference before restorative work is commenced.

Avoid placement of the junction between the restorative materials and tooth surface where the MIP occlusal contact will be (Figure 13).

In the case of PFM crowns, it is important to keep the porcelain-metal junction 2mm from the MIP occlusal contact (Figure 13).

It is preferable to place the occlusal contact on the metal and not on porcelain (abrasive).

To avoid chipping of the porcelain, maximum thickness of porcelain should not exceed 2mm.

When all-porcelain restorations such as zirconia are considered, the zirconia substructure may be extended incisally or occlusally to support the ceramic veneer at the incisal edge and the cusp, respectively.

When the plan is to use a cantilever bridge, only one tooth is replaced and the pontic should be out of contact in all excursive mandibular movements.

A custom-made incisal guidance is considered when the palatal surface of the upper anterior teeth are to be involved in the new restoration.

In patients with para-functional habits, an occlusal splint is indicated for protection of restorations and teeth.

Avoid its failure. Well-described laboratory instructions, including materials to be used and the design of the restoration, should be sent to the laboratory, along with the impression and a transfer bow-record.

**Functional assessment: examination of an occlusion**

The masticatory system and occlusion of each patient should be examined before any treatment is carried out to avoid potential damages. Start by asking the patient if they experience any signs and symptoms of functional impairment. The examination should include extra- and intra-oral examinations.

The functional assessment of occlusion, including extra- and intra-oral examinations, is summarised in Table 2.

**Dental implants and occlusion**

Dental implants are considered to be an integral part of restorative treatment, as they are widely used. Implants react to occlusal loading in a different way to natural teeth. This is because of the intimate contact between the implants and bone, and the lack of periodontal ligaments. As a result of the presence of periodontal ligaments and their viscoelastic properties, when teeth are loaded, they move within the socket with lateral movements that range from 56-108mm and apical movements that range from 25-100mm. On the other hand, when implants are loaded, they move laterally 10-50mm and apically 3-5mm, mainly as a result of peri-implant bone deformation. Furthermore, when a tooth is opposing another tooth, the occlusal thickness perception is about 20μm, while when implants oppose teeth the thickness is approximately 48μm. These collectively indicate that implants are less sensitive to occlusal loading than natural teeth. This may lead to the conclusion that implant-supported restorations are more liable to damage from occlusal loading than tooth-supported restorations. Therefore, it is important to protect the implant-supported restoration and the implant itself from negative effects that may be introduced by improper occlusion.

**Implant-protected occlusion**

Implant-protected occlusion was originally developed by Misch and aimed at...
reducing the occlusal forces on implant prosthetics.\textsuperscript{24-27} It consists of the following:

- incisal guidance;
- bilateral stability and occlusal contacts in MIP;
- freedom in centric (long centric);
- evenly distributed occlusal contacts and forces; and,
- smooth lateral excursive movements without working and non-working side interferences.

Basically, the outcome of this treatment is production of an ideal occlusion.\textsuperscript{24,28} Therefore, to optimise the occlusion with dental implants several factors should be considered and implemented whenever possible. For instance, a long centric occlusion (in which the MIP and CR do not coincide but are in the same horizontal level) should be used. This requires elimination of any occlusal interferences between MIP and CR. To achieve this target, flat fossae and grooves should be incorporated into the occlusion of the restoration. It is also important to create shallow cusp inclination in order to avoid torque, because with every 10-degree increase in cusp inclination, there is an approximately 30% increase in torque magnitude. Therefore, reduced cuspal inclination leads to less non-axial loading. Furthermore, occlusal table width should be 30–40% smaller in a molar region, as a wider occlusal table than the implant diameter can cause cantilever effects and bending, but a smaller occlusal table than the implant diameter will cause occlusal forces to be axially directed.

Cantilevering, which is usually created whenever a force is applied at a distance from the fulcrum, should be avoided when possible. It is recommended that the anterior guidance should be shallow to a degree that allows disclusion of the posterior teeth during lateral and protrusive mandibular movements. A shallow incisal guidance (minimum vertical overlap) generates less loading on the anterior implants than when the guidance is steep. It is also important to protect restoration and implant by occlusal splints whenever possible.

**How to check occlusion on implants**

Light force and thin articulating paper (less than 30μm) are used. The occlusal contact on the implant-supported restoration is then relieved. This will place all occlusal forces on the adjacent teeth, while the implant-supported restoration is out of contact with the opposing implant/tooth. Next, a greater occlusal force is applied. If the contact is heavier on the implant, it should be relieved in order to achieve equal contact on both the implant-supported restoration and the teeth. Hence, the occlusal forces are shared between the implant and the teeth.

**Conclusion**

One of the main requirements of restorative treatment is to achieve at the end of the treatment dental occlusion that does not deleteriously affect the stomato-gnathic system. Consequently, knowledge of the basic principles of dental occlusion and the masticatory system is vital for every dental student and dentist. Therefore, functional assessment and examination of occlusion should be considered and carried out on a routine basis.

In restorative dentistry, when a patient attends a dental clinic for treatment, the required treatment may involve a small or major alteration in the occlusal surfaces of the teeth. In the former case, the conformative approach can be implemented, as little or no alteration in the occlusion will take place and the original MIP is used as the treatment position. In the second case, as more complex restorative treatment is required, the reorganised approach should be implemented.

When a dental implant is considered, a basic knowledge of how the implants are loaded is of paramount importance, as the way in which the implant is loaded differs from that of the teeth.

**References**


Erratum
In part I of this article (*Journal of the Irish Dental Association* 2015; 61 (4): 201-208), the reference in the caption for Figure 11 was omitted. The reference is: “Adapted from Craddock & Youngson (2004)”. We apologise for this error.