S. GRACIS
F. GALLI
L. FUMAGALLI

14

Occlusion in Implant-Supported Prostheses Under Immediate Loading and Delayed Loading

14

The development of the proper occlusion in an implant-supported prosthesis is a critical step in the execution of a treatment that requires the replacement of one or more teeth.[1–3] This is true when fabricating not only the definitive restoration, but also the provisional restoration, particularly when employing the immediate loading protocol with its main goal of achieving osseointegration.

If an excessive occlusal load acts on a definitive implant-supported prosthesis, it can cause mechanical complications (eg, loosening of retention screws, breakage of implant components, chipping of ceramic veneering material, crown decementation)[4] (FIGS 14-1 AND 14-2); it can also compromise the supporting bone[5–7] and lead to muscular and/or joint dysfunction.[8] Occlusal overload on a provisional prosthesis under immediate loading can compromise osseointegration, even in cases in which satisfactory primary stability had been achieved at the time of implant placement. Therefore, the presence of a malocclusion, wear facets, or parafunctional habits must be carefully evaluated before treatment is initiated to allow for the planning and construction of a prosthesis that will be stable from an occlusal point of view, in harmony with the patient's functional movements, and capable of serving over time.

This chapter provides an overview of the different occlusal schemes that should be used in various types of immediate loading provisional and definitive restorations. In some cases, the recommendations are not supported by scientific evidence because of the objective impossibility of acquiring irrefutable data and are thus a synthesis derived from the authors' direct clinical experience. The goal is to provide suggestions on how to create a stable occlusion in which forces are distributed equally and atraumatically on the supporting abutments. However, these indications cannot be considered absolute rules that protect the patient (and the clinician) from the possibility of complications or failures. The capability of the clinician to apply the general principles outlined here to the individual reality of the single clinical case, adapting them and, where necessary, modifying them is still of fundamental importance. This capability is strictly bound to the knowledge one must acquire in order to evaluate correctly the condition of any patient (see chapter 5). As a matter of fact, the performance of a complete evaluation is the foundation of an accurate diagnosis and the formulation of a well-devised treatment plan with a realistic prognosis for the individual teeth, implants, and dentition as a whole.

DIFFERENCES BETWEEN IMPLANTS AND NATURAL TEETH

Implants differ from natural teeth in many ways. The periodontal ligament of natural teeth provides a degree of resilience that varies depending on the number of roots the tooth possesses and the amount of periodontal support. Thus, there is a difference in the occlusal contacts found in gentle closing and those found in tight clenching. If there is occlusal overloading (trauma), mediation by the periodontal ligament allows the effects to be reversible.

In the case of an implant, because it is in direct contact with the alveolar bone, the transfer of occlusal forces (and hence the behavior of the bone itself) is modified. It has been demonstrated, initially in the orthopedic field and subsequently in implant dentistry, that the peri-implant bone subjected to a functional load is in a state of continual remodeling and that there is a state of equilibrium between bone formation and bone resorption processes.[9,10] As the load is absorbed by the bone, microstrains that stimulate bone growth are generated, as demonstrated by the presence of osteoblasts.[10] Bone remodeling of 36% per year by volume has been reported to have occurred around an implant that was submerged for 12 months (and, therefore, not subjected to prosthetic load). After 3 months of loading, the percentage of sites with active bone formation had increased by as much as 676% on a yearly basis.[11]

This continual dynamic adaptation can take place only below a certain threshold of occlusal load. When this threshold is exceeded, as in situations of overloading, cells of the osteoclastic type are recruited and bone resorption mechanisms prevail with a consequent reduction in peri-implant support.[12] Research to date has not succeeded in demonstrating acceptable values for the occlusal load, and it is generally agreed that these may differ among patients.

The fact that implants are ankylosed does not mean that they are absolutely immovable. There is a possibility of movement generated by the deformation (though minimal) of the bone component in which the implant is inserted. The degree of deformation differs foremost depending on bone quality. Bone types 1 and 2 (according to the classification by Lekholm and Zarb[13]) are less resilient than bone types 3 and 4. The length of the implant body also influences the rigidity of the system, bone quality being equal. Short implants anchored only in the superficial cortical bone comprise a more resilient system than long implants, particularly if they are also anchored in cortical bone apically.[14,15]

In a natural tooth, the periodontal ligament also serves a proprioceptive function that activates reflex controls by the central nervous system. The absence of proprioceptors in the peri-implant zone might, during masticatory cycles, preclude the immediate activation of this neuromuscular feedback that acts to protect the implant-prosthetic unit. However, scientific findings are not in full agreement over how tactile perception differs in implants versus natural teeth in a qualitative nor a quantitative aspect.[13,16–18] It has been reported[19] that, when the teeth come into contact, they can perceive interferences of 20 μm, whereas an implant opposed to a tooth can perceive interferences of 48 μm, and two antagonist implants can perceive interferences of 64 μm. In complete rehabilitations supported by implants, values as high as 108 μm may be found. Although some research[20] has shown that the capacity of a patient with implants to perceive rapid changes in load remains essentially unaltered, a different study[21] found implants to be less sensitive than teeth in perceiving small loads that are prolonged over time. This implies that the patient is not able to help the clinician identify and locate possible occlusal prematurities.

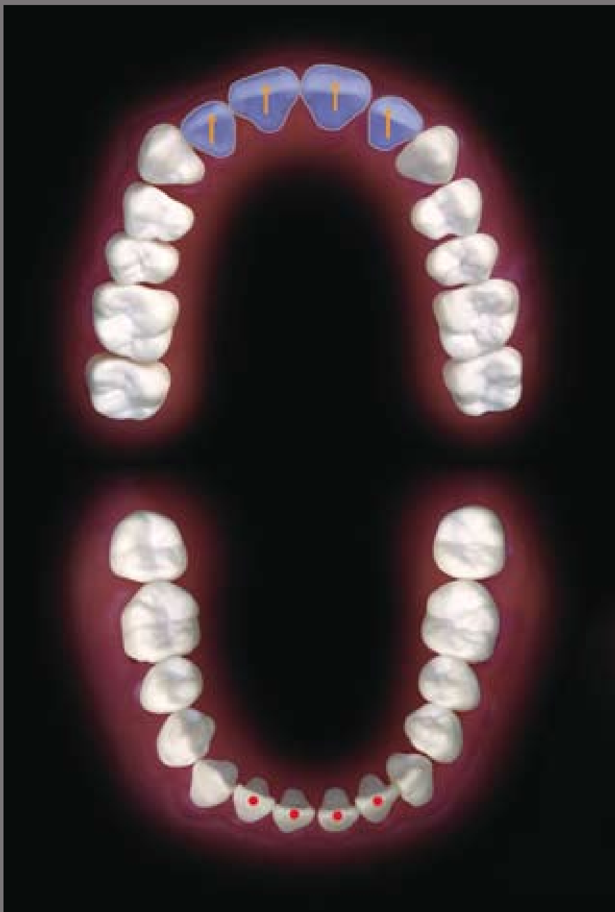
Another difference and complication arises because the implant is not a single body but rather is made up of multiple stages. The type of connection between these stages and the components and protocols used for transferring the implant position to the laboratory together lead to differing degrees of tolerance, imprecision, deformation, and resistance to loads. If, in addition, one takes into consideration the fact that the dental technician works on rigid casts, it is easy to understand how difficult, indeed impossible, it is to reproduce occlusal contacts that are immediately compatible with and can be integrated into the

1

2

Fig 14-1 → Early wear of the cusps of composite resin teeth in an implant-supported definitive prosthesis.

Fig 14-2 → Fatigue fracture of abutment screws in a prosthesis of two splinted units (mandibular left second premolar and first molar) in a patient with parafunctional habits after 3 years of loading.

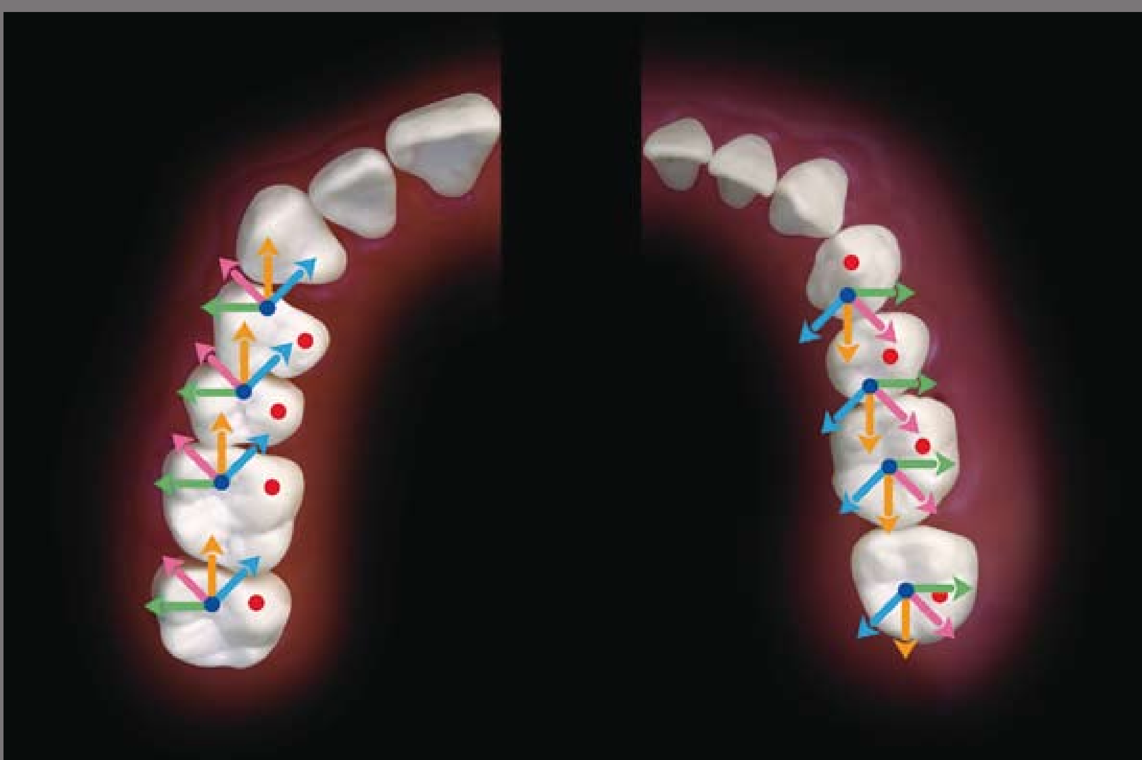


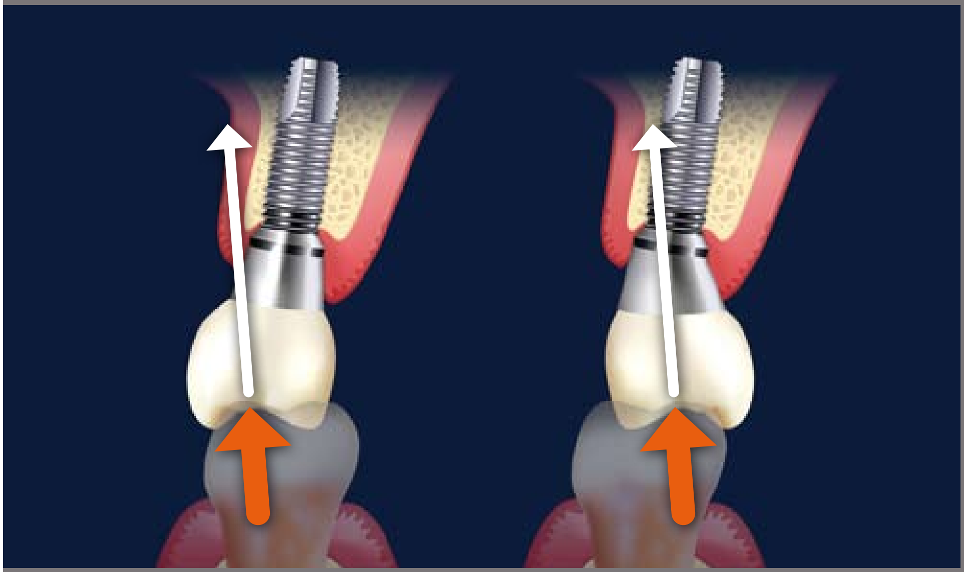
3

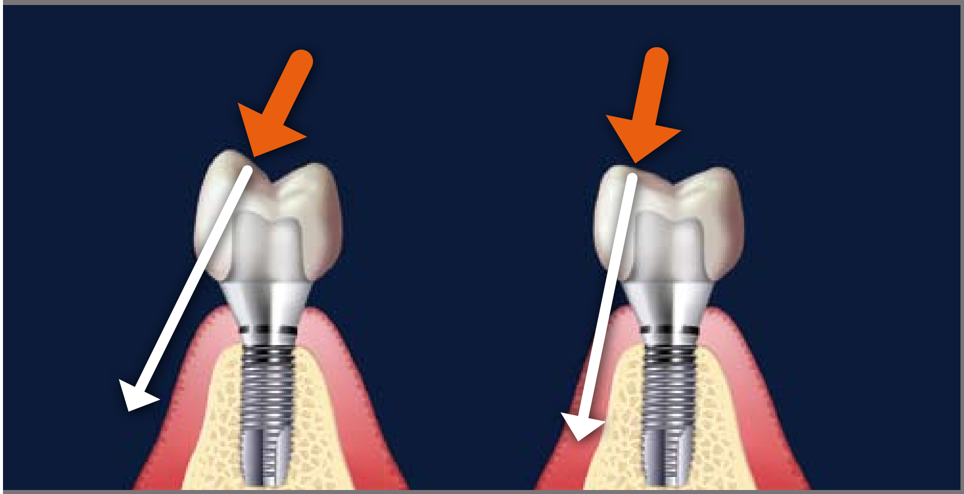
4

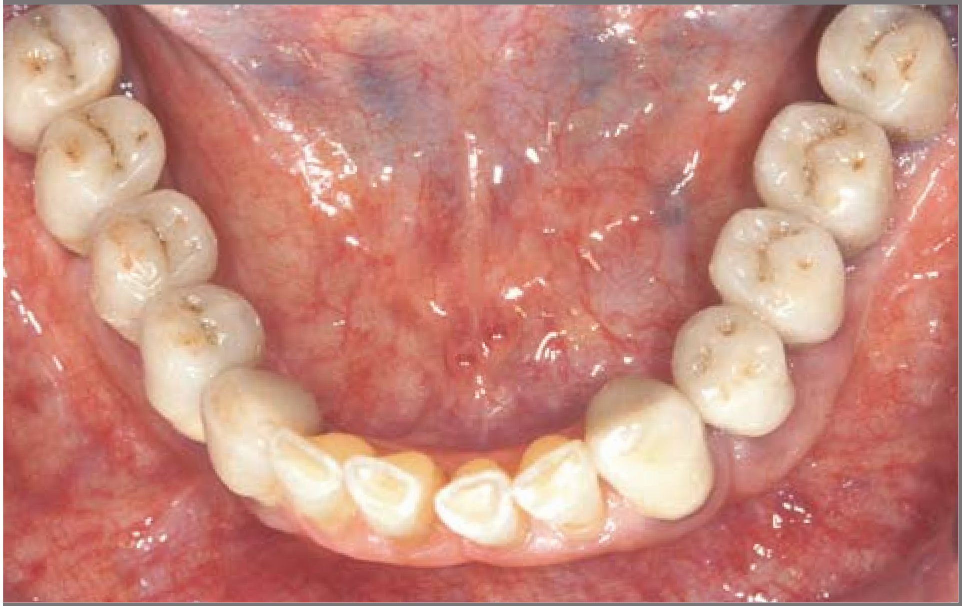
Fig 14-3 → Direction of the pathways in protrusion from the maximal intercuspal position. All four incisors need not necessarily be in contact throughout the entire movement.

Fig 14-4 → Direction of possible pathways of the centric cusps starting from the maximal intercuspal position during excursive movements. In planning the occlusal scheme, it is important to design and respect the escape grooves for working side and balancing side occlusal movements.









5

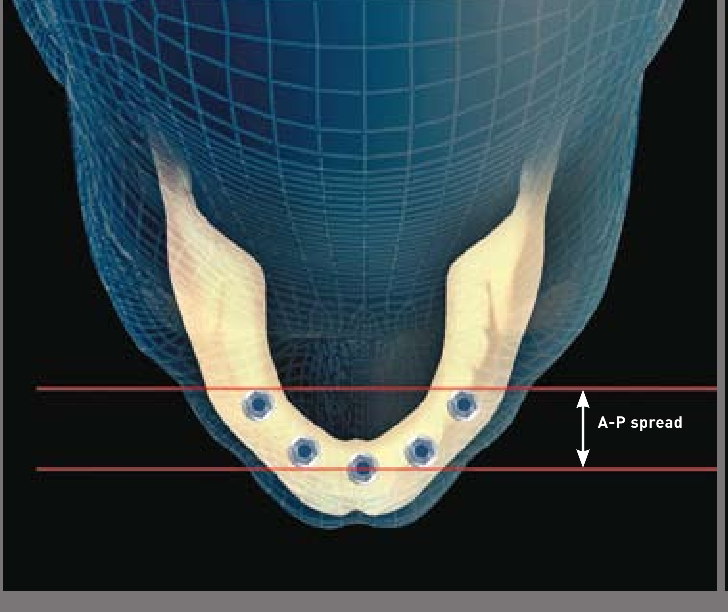
6

7

Fig 14-5 → When implants are positioned palatally, in order to avoid an unfavorable prosthetic configuration (left), an occlusal scheme with a crossbite can be created to bring the load vectors as close as possible to the implant axis, reducing cantilever arms (right).

Fig 14-6 → Classic contouring of the occlusal table of the posterior teeth tends to create force vectors with a projection distant from the implant body (left). Contouring the cusps in such a way to reduce the inclined planes has been suggested as a strategy to reduce bending moments (right).

Fig 14-7 → Posterior crowns supported by implants. To reduce the occlusal load, it is suggested to create a premolar shape for the implants positioned in the molar region.



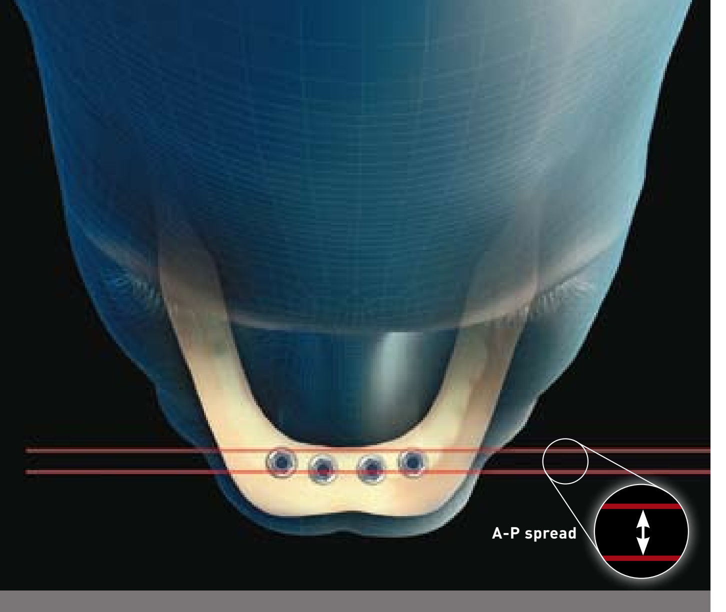
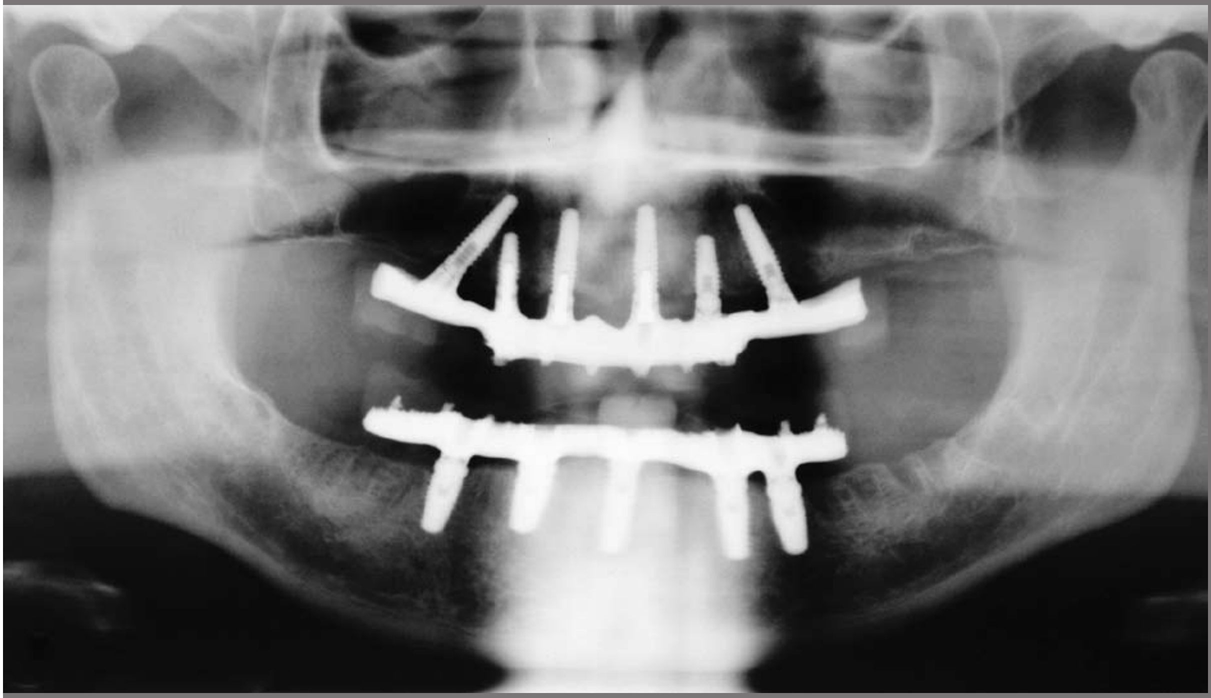
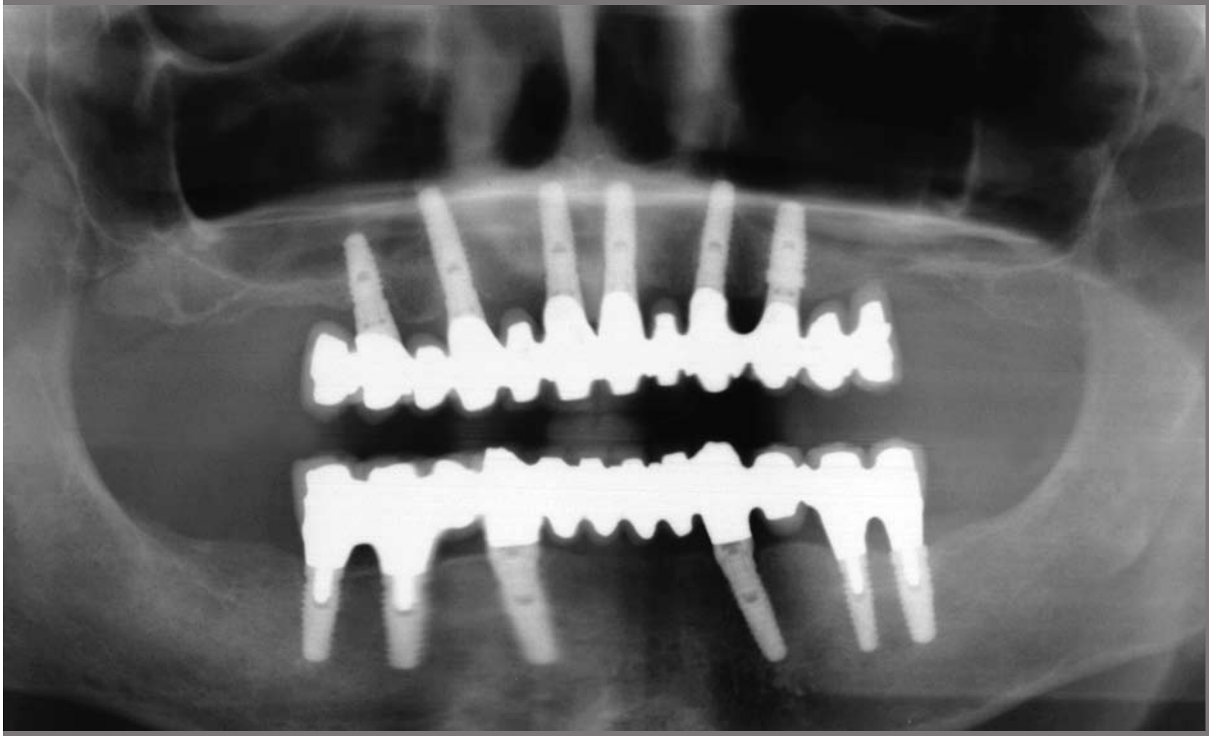


Fig 14-8 → Because of the inclination of the teeth in the anterior area, contacts must be grazing to prevent perpendicular forces from developing and overloading the prosthetic components and the supporting bone.

Fig 14-9 → The shape of the mandible can influence the number and arrangement of the implants. A U-shaped mandible that follows a good arc is optimal for a traditional implant-prosthetic design with upright implants placed interforaminally.

Fig 14-10 → If the mandible has a square shape, it is recommended to plan an implant-prosthetic construction with tilted posterior implants to improve load distribution.





11

12

Fig 14-11 → Panoramic radiograph showing an example of screw-retained implant-supported prostheses with distal cantilever in the mandible and maxilla.

Fig 14-12 → Panoramic radiograph showing an example of a cement-retained prosthesis without a distal cantilever in the mandible and with a short distal cantilever in the maxilla.

13A

13B

Fig 14-13a → Metal prosthetic framework veneered with composite resin for the rehabilitation of a patient with an edentulous mandible. The cusps are clearly evident on the occlusal surface.

Fig 14-13b → The same prosthetic structure after 9 years of function opposite a complete denture with resin teeth. Note the severe abrasion of the cusps resulting in the enlargement of the occlusal table.

patient's oral system.[22] All of these differences may generate discrepancies, even large ones, at the occlusal level, which become evident once the prosthesis is inserted into the patient's mouth. Therefore, greater attention must be paid to the precision of occlusal contacts when producing implant-supported prostheses compared with prostheses supported by natural teeth.

OCCLUSAL SCHEMES FOR PROSTHESES SUPPORTED BY NATURAL TEETH

Occlusal concepts were first developed to rehabilitate patients with complete dentures in a fully balanced occlusion (cross-arch, cross-tooth, and in protrusion). According to this scheme, it was necessary to create simultaneous and equal contacts between all opposing teeth of both arches, in static occlusion as well as during lateral and protrusive movements. This type of occlusion plays a fundamental role in removable complete dentures because it stabilizes them against displacement in an empty mouth.

Subsequently, balanced occlusion was used also for the natural dentition. It was thought that by maintaining these idealized occlusal contacts during all movements, potential tooth interferences and, likewise, strain on muscles and joints could be eliminated. Furthermore, by distributing contacts among a larger number of teeth, it was thought possible to reduce the load on each individual tooth, with consequent reduction in bone resorption.

In the second half of the 1950s, gnathologists including Schuyler, Stallard, Stuart, and McCollum began to report failures in rehabilitations that respected the rules of balanced occlusion, leading them to question the validity of this concept.[23–25] There was, thus, a move away from a concept of fully balanced occlusion, in which all teeth were working together, toward a concept of mutual protection in which the functionality of the occlusion was the result of different roles played by the teeth and of the antagonism between different groups: anterior teeth versus posterior teeth and posterior working teeth versus posterior nonworking teeth. This scheme aimed to produce a situation in which one group of teeth protected another group in all occlusal positions.

For lateral guidance, there are two schools of thought:

- Group function or guidance (functionalists' concept): There should be maximum contact of teeth in centric relation, simultaneous contact of anterior and posterior teeth on the working side during lateral excursions, and no contact on the nonworking side. This approach is indicated if the canine is mobile because of reduced periodontal support or in patients with little anterior guidance (reduced overbite); contacts should decrease in intensity from the anterior to the posterior sector.
- Canine-protected occlusion (modern gnathologic concept): The canine protects all the other teeth. None of the posterior teeth, neither on the working side nor on the nonworking side, contact during any lateral movement.

The two approaches share the following precepts:

- In the position of intercuspation, the forces must be applied axially on the posterior teeth and the contacts must be simultaneous bilaterally and pointlike, whether the conformational approach (maximal intercuspal position) or the reorganizational approach (centric relation) is applied. The decision to rehabilitate the patient in one or in the other position depends on the extent of the prosthetic rehabilitation (number of teeth involved) and on whether the original vertical dimension is maintained or is to be changed. In patients in whom the vertical dimension must be increased or the existing occlusion must be modified extensively, it is preferable to use centric relation.[26]

- The incisal guidance must be sufficiently steep to enable disocclusion of all posterior teeth in protrusion (FIG 14-3), whereas the working lateral guidance must be sufficiently steep to enable disocclusion of all teeth on the nonworking side (there must be no posterior balancing interferences). These movements must be linear, and they should not generate lateral deviations along the pathway. The articulating paper must trace on the tooth surfaces; narrow pathways rather than wide areas of contact.

Either of these approaches may be appropriate. The decision must be made case by case, based on an evaluation of the existing relationships, mobility, and crown-to-root ratio.

An analysis of the relationship between overbite and overjet, the indices of vertical and horizontal superpositioning of the dental arches, is of fundamental importance. Patients with deep overbite and reduced overjet have immediate disocclusion of the posterior teeth. Patients with deep overbite and large overjet, as in the case of skeletal Class II, division 1, have a lack of anterior guidance. This skeletal dysplasia can be effectively addressed with an orthodontic-orthognathic approach, if necessary, prior to the implant-prosthetic rehabilitation.

Occlusal contacts in the maximal intercuspal position should ideally fall on the buccal cusps of the mandibular teeth and along the line of the central fossae of the maxillary teeth, whereas the palatal cusps of the maxillary teeth come into contact along the line of the central fossae of the mandibular teeth. There may be more than one point of contact per pair of antagonist teeth, but it is imperative that they are simultaneous and balanced between the two hemiarches. Creation of multiple points of contact, ie, tripodized occlusal contacts, even if it is optimal from a theoretical standpoint, is clinically difficult to achieve. A single point of contact per cusp is sufficient and is easier to execute.[27] In occlusal modeling, it is important that escape grooves for working and nonworking movements are designed and respected (FIG 14-4). Lack of escape grooves can cause deviations in the mandibular pathway and increase occlusal loads on some teeth. Box 14-1 summarizes the goals of correct occlusion on natural teeth.

OCCLUSAL SCHEMES FOR IMPLANT PROSTHESES

The occlusal schemes for implant prostheses are borrowed from those for prostheses supported by natural teeth, but with some differences because implants display no significant resilience under load. In particular, in a situation with teeth and implants, it is preferable, whenever possible, to develop excursive guid-

Bilateral point contacts on the posterior teeth
No contacts on the anterior teeth in maximal intercuspal position
Disocclusion of all posterior teeth in lateral and protrusive movements
When rehabilitating in maximal intercuspal position, no occlusal prematurity on the prosthesis during excursions to centric relation position

Box 14-1 → Goals of correct occlusion on natural teeth ance on the natural teeth, thus avoiding nonaxial loads on the implant-supported prosthesis. Particular attention should be paid to the size and shape of the crowns for posterior implants and to the position and extent of contacts to reduce bending loads as much as possible.

Reduction of bending loads on implant-prosthetic structures can be achieved in different ways. First, points of contact should fall as centrally as possible above the implant. This is desirable even when employing implants with an internal connection that, from a mechanical standpoint, respond better to transverse forces and have less stress on the connecting screws during occlusal contact than do external connection implants.

The greater the diameter of the implants used in the posterior areas, the higher the percentage of occlusal forces that will have a compressive axial direction and will, therefore, be better tolerated and distributed by the implant-prosthetic system. However, the use of such implants is limited depending on anatomical conditions at the surgical site.

If implant position is not prosthetically guided, the resulting crown will more likely generate eccentric, bending loads. For example, in rehabilitating a moderately atrophic maxilla that has undergone bone resorption of the centripetal type, the clinician may have to restore implants that are located too palatally if the patient declines bone regeneration, surgically assisted rapid palatal expansion, or Le Fort I procedures that would be needed to restore the correct maxillomandibular transverse relationship. In these cases, it is preferable to create a lingualized occlusal scheme and appropriately modify the shape and dimension of the antagonist cusps to reduce lateral loads[28] (FIG 14-5).

One of the strategies that has been proposed concerning the shape of the implant crown entails reducing the height of the cusps. This reduces the steepness of the cusps' inner inclines so that the occlusal forces applied on the prosthesis run closer to the implant axis[28–30] (FIG 14-6). However, from a clinical standpoint, it has been shown that this strategy does not have an important positive impact.[31]

The factor that most influences the magnitude of the bending force generated at the implant's interface is the consistency of the food bolus: the harder and tougher the food, the greater the force required to penetrate the bolus. This factor cannot be controlled a priori.[32] However, one useful strategy to decrease the load on implants is to fabricate crowns with a reduced occlusal table width (30% to 40%) compared with a prosthesis on natural teeth.[28,31] According to this line of thought, the prosthetic crown would be similar in shape and dimension to a large premolar, even for wide-diameter implants (5 or 6 mm) (FIG 14-7).

The occlusal schemes appropriate for patients with implants differ depending on the type of edentulism (single-tooth, multiple-teeth, or complete), loading protocol (immediate or delayed), and definitive prostheses (fixed or removable). The strategies to be adopted in making a provisional prosthesis under immediate loading circumstances serve to maximize the chances of achieving the primary goal of obtaining osseointegration at the end of the healing period. Table 14-1 summarizes the occlusal schemes described in the following sections for immediate loading and definitive implant-supported prostheses for different types of edentulism and restorations.

SINGLE-TOOTH EDENTULISM

In the case of a single implant, it is recommended to eliminate from the immediately loaded provisional crown any occlusal contact in maximum intercuspation and in lateral movements.[33–36] For single posterior teeth in particular, it can be useful to reduce the buccolingual width of both occlusal table and crown. Once osseointegration has been achieved, the patient's treatment can be finalized with a definitive prosthesis that restores contacts and guidance, as described in the following sections.

Anterior tooth

In the anterior area, the maximal intercuspal position contact of the definitive crown must be absent or grazing (almost touching); it must be possible to pull out an occlusal foil of approximately 8- to 12-μm thickness without tearing it. Hard contact should be avoided because of the reciprocal inclination between teeth and implants; such contact would generate a force almost perpendicular to the implant axis, causing stress in the prosthetic components and in the bone (FIG 14-8). During lateral and protrusive movements, contact on the crown should be avoided altogether if possible.

Posterior tooth

The type of occlusion on the posterior definitive restoration must be planned to minimize the occlusal forces on the implant and to distribute forces to a greater extent onto the neighboring natural teeth. In the maximal intercuspal position, it is preferable that the contact be localized in the central fossa rather than on the marginal ridge. There must be no contact when the patient closes without clenching (ie, it must be possible to pull out the occlusal foil) and only slight contact when clenching.[36] However, some clinicians consider this strategy invalid because the opposing tooth may extrude over time, establishing an occlusal contact even when applying normal functional forces. Furthermore, occlusal contacts generate forces that are, for the most part, axial (unless the buccolingual and mesiodistal dimensions of the crown are considerably larger than the implant diameter and become eccentrically loaded). These are the forces best withstood by the implant-prosthetic construction because the various stages, being loaded by compressive forces, are adapted one upon the other. From a mechanical standpoint, this compression is the most favorable stress. The bone also reacts favorably to axial forces because an implant possessing an external macro- and microgeometry compresses the bone grown into the space between the screw threads' ridges in contact with the implant surface. Thus, in the authors' view, it is important that the patient does not perceive the contact on the implant crown as being present or, worse, prevalent.

In lateral movements, neither working side contacts nor balancing occlusal contacts must be present. These types of contact are frequently visualized with marking paper as lines running up the cusps. In this case, it is appropriate to reduce or eliminate these contacts by adjusting the inner inclines of the cusps and by increasing the width of the fossa. If the cusps interfere in excursive movements, they may be reduced, but not before the central fossa in the antagonist tooth has been filled. Modification of the antagonist also is a valid concept when spontaneous extrusion of the teeth comes about following prolonged edentulism. A prosthesis that becomes decemented from an implant abutment may indicate that the restoration is overloaded, which is frequently caused by the presence of an occlusal prematurity.

MULTIPLE MISSING TEETH

In cases of multiple tooth replacements, the goal of minimizing or preventing loads on the immediate provisional prosthesis is not as easily achieved as in the case of single teeth. The difficulty depends on the number of missing teeth and their position. If implants are being placed in a distal edentulous ridge or if the natural tooth at the distal end does not have an antagonist, it will be impossible to avoid an occlusal load. Thus, it is important to reduce the buccolingual dimension of both crown and occlusal table.

In lateral movements, both working side and balancing occlusal contacts on the prosthesis must be avoided. Should this not be possible, it is suggested to minimize the amount of overbite and to create guiding pathways that are as shallow as possible while still ensuring disocclusion of the posterior teeth.

Table 14-1 → Occlusal schemes for immediate loading and definitive implant-supported prostheses

(Stefano Gracis and Fabio Galli, 2009)

TYPE OF EDENTULISM		TYPE OF RESTORATION	OCCLUSAL SCHEME IN IMMEDIATE LOADING
SINGLE TOOTH	ANTERIOR	**Single Crown**	• No static or dynamic contact with antagonist teeth
	POSTERIOR	**Single Crown**	• No static or dynamic contact with antagonist teeth • Reduction of buccolingual width of occlusal table and buccolingual dimension of crown
MULTIPLE TEETH	ANTERIOR	**Splinted units or single crowns**	• Splint the elements • No static contact with antagonist teeth • Where possible, maintain excursive guidance on natural teeth • Otherwise, minimize vertical superimposition (overbite) and create guidance pathways that are as flat as possible, ensuring disocclusion of posterior teeth
	POSTERIOR	**Splinted units or single crowns**	• Splint the elements • Where possible, no static or dynamic contact with antagonist teeth • Otherwise, slight contact and marked reduction of buccolingual width of occlusal table and of buccolingual dimension of crowns • If maxillary implants are positioned palatally, create crossbite lingualized occlusion to reduce cantilever arm and improve axial loading
COMPLETE EDENTULISM	MAXILLARY OR MANDIBULAR	**One-piece fixed prosthesis with posterior cantilevers or removable prosthesis (overdenture) on milled bar supported exclusively by implants**	• Avoid or minimize length of cantilevers • Simultaneous bilateral point contacts on all teeth, excluding teeth distal to implant emergence • In lateral movements, group function or guidance with flat linear pathways and minimal vertical superimposition, excluding teeth in the cantilever • In protrusive movements, guidance distributed on all anterior teeth, including canines, with flat linear pathways and minimum vertical superimposition • Even if the implant-supported prosthesis is opposed by a removable full denture, in excursive movements, avoid balancing contacts at the cost of making the prosthesis unstable
		Fixed prosthesis without posterior cantilevers (in one or more pieces)	• Simultaneous bilateral point contacts on canines and posterior teeth and absence of static contact on incisors • In lateral movements, group function or guidance with flat linear pathways and minimum vertical superimposition • In protrusive movements, guidance distributed on all anterior teeth, including canines, with flat linear pathways and minimum vertical superimposition • Even if the implant-supported prosthesis is opposed to a removable full denture, in excursive movements avoid balancing contacts at the cost of making the prosthesis unstable
		Removable prosthesis (overdenture) on single retention devices or on cast bar supported by implants and mucosa	If possible, do not use a removable prosthesis for immediate loading. If there is no alternative, follow these guidelines: *Opposed to natural dentition or a fixed prosthesis:* • Simultaneous bilateral point contacts on canines and posterior teeth and absence of static contacts on incisors • In lateral movements, group function or guidance with flat linear pathways and minimum vertical superimposition • In protrusive movements, guidance distributed on all anterior teeth, including canines, with flat linear pathway and minimum vertical superimposition *Opposed to full denture:* In excursive movements, seek one or more balancing occlusal contacts

	OCCLUSAL SCHEME FOR DEFINITIVE PROSTHESES
	• No or slight contact with antagonist teeth in static occlusion • Avoid contacts in excursive movements
	• Slight occlusal contact with antagonist teeth when clenching; no contact when patient closes lightly (contact on implant crown must not be perceived as present or, worse, prevalent) • No contact in excursive movements
	• The decision whether to splint the implants depends on the following factors: number of implants in relationship to number of missing teeth; crown-to-implant ratio; bone quality; transverse relationship with antagonist teeth; and presence of parafunctional habits • No contact or slight contact with antagonist teeth in static occlusion • Where possible, maintain excursive guidance on natural teeth • Otherwise, minimize vertical superimposition (overbite) and create guidance pathways that are as flat as possible, ensuring disocclusion of posterior teeth
	• Occlusal point contacts that are not prevalent over the contralateral side but avoid excessive loads on anterior teeth (no fremitus) • No contact in lateral movements with antagonist teeth unless the canine is also included • Moderate reduction of buccolingual width of occlusal table and of buccolingual dimension of crowns • If maxillary implants have been placed palatally, create crossbite lingualized occlusion to reduce cantilever arm and improve axial loading • Avoid posterior extensions
	• Simultaneous bilateral point contacts on canines and posterior teeth and grazing contacts on incisors • In lateral movements, canine guidance or group function with flat linear pathways and minimum vertical superimposition • In protrusive movements, guidance on anterior teeth with flat linear pathways and minimum vertical superimposition • If the implant-supported prosthesis is opposed to removable complete denture, leave the most distal tooth slightly out of occlusion and, in excursive movements, seek one or more balancing contacts, planning greater anteroposterior space at the anterior teeth
	• Simultaneous bilateral point contacts on canines and on posterior teeth and grazing contacts on incisors • In lateral movements, canine guidance or group function with flat linear pathways and minimum vertical superimposition • In protrusive movements, guidance on anterior teeth with flat linear pathways and minimum vertical superimposition • If the implant-supported prosthesis is opposed to a removable complete denture, in excursive movements seek one or more balancing contacts, planning greater anteroposterior space at the anterior teeth
	Opposed to natural dentition or fixed prosthesis: • Simultaneous bilateral point contacts on canines and posterior teeth and no static contacts on incisors • In lateral movements, group function or guidance with flat linear pathways and minimum vertical superimposition • In protrusive movements, guidance distributed on all anterior teeth, including canines, with flat linear pathways and minimal vertical superimposition *Opposed to complete denture:* In excursive movements, seek one or more balancing occlusal contacts

To reduce the risk of failure due to localized overloading, it is strongly recommended to splint multiple adjacent implants, whether anterior or posterior, with the provisional prosthesis. Once osseointegration has been achieved, the next step is to evaluate whether to maintain the implants splinted in the definitive prosthesis or to restore them individually. For this purpose, the following factors must be evaluated: number of implants in relationship to the number of missing teeth; crown-to-implant ratio; bone quality; transverse relationship with the antagonist; and presence of parafunctional habits.[37–39] If in doubt, it is preferable to splint the implants.

Anterior area

In the anterior area, all contacts in closing and, where possible, during excursive movements must be eliminated from the provisional prosthesis. It is also important to decrease the amount of overbite. During the healing period, this may make it necessary for some posterior teeth to participate in the disocclusion. If this is not possible, then it will be necessary to create guidance pathways that are as flat as possible to reduce transverse loads.

In the definitive prosthesis, slight occlusal contact with the antagonist teeth is acceptable, and effective protrusive guidance can be restored, even with the contribution of implant-supported crowns whose guidance pathways should be relatively flat. Absence of fremitus and fluidity of movements performed by the patient are proof of correct functional modeling.

If the canine is one of the teeth replaced by the implants, it should be splinted to the other implants, and canine-protected occlusion should be employed provided that the inclination of the palatal aspect is not excessively steep.

Posterior area (intercalated or distal free end)

When two or more teeth have to be restored, the occlusal scheme recommended follows the same concepts explained above: reduction of the buccolingual width of the occlusal table and of the buccolingual dimension of the crowns, contact points in the cusp-to-fossa relationship, and no working side or balancing occlusal contacts in lateral movements. Occlusal contacts must not be more prevalent than those of the contralateral side, but, at the same time, they must avoid excessive loading of the anterior teeth, which is revealed by the presence of fremitus.

Frequently, in the posterior areas of the maxillary arch, bone resorption following tooth loss leads to palatal positioning of the implants, unless bone regeneration procedures are employed to enable the implants to occupy the position of the buccal roots of the lost teeth. To decrease the buccopalatal cantilever arm and to improve axial loading, in these cases, it is recommended to establish an occlusal scheme with a crossbite, bringing the buccal maxillary cusps into contact with the fossae of the mandibular teeth. It is also important to avoid fabricating prostheses with posterior extensions or cantilevers.

In some cases, it is possible to splint the implants to the natural teeth. However, the appropriateness of this approach must be carefully evaluated because the literature suggests that it leads to a higher rate of complications than rehabilitations on implants alone.[40] The recommendations to be followed in these cases are principally three: *(1)* select teeth with an optimal prognosis and minimal mobility; *(2)* splint teeth and implants together rigidly; and *(3)* enable independent removal of the prosthesis on the implants. Connection through rigid structures is fundamental. It has been shown that, over time, nonrigid connection is associated with intrusion of the natural teeth, but a causal relationship has not been demonstrated.[41–43]

COMPLETE EDENTULISM

In provisional immediate loading prostheses for completely edentulous arches, the occlusal scheme must reduce lateral loads and distribute them as far as possible across the entire prosthesis. Cantilevers must be avoided or very much reduced.

All of the teeth, except for those in extension, should make contact in static occlusion and should have group function in lateral movements. During the period of osseointegration, the physiologic adaptation of the muscle-condyle complex can be evaluated, and if necessary, any changes can be made to the provisional prosthesis—possibly without removing it. It is important to schedule periodic occlusal checkups, which can also be used to ensure that the screws retaining the provisional prosthesis to the implants are tight (or, in the case of cement-retained structures on provisional abutments, the cement has not washed out). Moreover, it is suggested[31] that the patient be kept on a soft diet during the period of healing and osseointegration.

It is preferable not to use prostheses of the removable type in immediate loading to avoid the risk of uncontrolled pressure on the soft tissues, especially in the first few weeks after surgery. When there is no alternative, it is recommended to reline the full denture with a rigid resin on healing abutments that protrude from the gingiva, thus avoiding pressure on the peri-implant zones.

Fixed prostheses with posterior cantilevers

A fixed one-piece prosthesis that is screw-retained to four to six implants positioned in the interforaminal zone of the mandible or in the anterior area of the maxilla is the type of prosthesis that has the longest-term clinical documentation. Traditionally, this prosthesis is made with posterior cantilevers that vary in length depending on bone quality, the vertical space available at the extension, and the type of dentition or prosthesis present in the antagonist arch.

In general, it is recommended to plan for a cantilever with a length not greater than the anteroposterior implant space (A-P spread) multiplied by a factor of 1.5[44,45] (FIGS 14-9 AND 14-10). The teeth on the cantilever should be limited in their buccolingual dimension to reduce the occlusal load. Keeping the teeth out of occlusion by 100 μm along the extension has been proposed to limit mechanical fatigue on the metal structure,[46] but this strategy only protects the extension in cases of parafunction. Cantilevers longer than 15 mm have a shorter survival time in the mandible than in the maxilla,[47] although some long-term studies appear to demonstrate the contrary.[48] In the maxilla, extensions of not more than 12 mm are recommended because of the poor quality of bone compared with that in the mandible[1,49,50] (FIG 14-11).

It is critically important that the apicocoronal and buccolingual thickness of the connector distal to the most posterior implants is of adequate size to avoid deformation or even breakage resulting from fatigue of the extension under load. In the case of a prosthesis with a metal structure veneered with acrylic resin, these dimensions should not be less than 4 mm in height and 3 mm in thickness, respectively.

In lateral excursions, it is recommended to create a canine-protected occlusion or, in borderline cases, group function with flat linear pathways and minimum vertical superimposition (overbite). The same recommendations hold for protrusion, where the separation of the posterior teeth should be guaranteed without creating excessive vertical overlap of the anterior teeth; this would create steep guidance and increase the labial forces acting on the maxillary teeth.

If the implant-supported prosthesis opposes a removable complete denture, it is recommended to leave the most distal tooth and the incisors slightly out of occlusion. It has been observed in these cases that the magnitude of the loads generated in the segments in extension is higher compared with rehabilitations opposed by natural dentition.[51,52] In excursive movements, in contrast, it is best to seek one or more balancing occlusal contacts to limit the risk of dislodgement of the complete denture.

Fixed prostheses without posterior cantilevers

Despite reports in the older literature that show encouraging results with implants located in the anterior area alone and with long cantilevers,[48] it should be remembered that the concentration of forces in the posterior sectors has been measured to be as much as four times greater than that in the anterior sectors.[53] This would appear to indicate that, when the quantity of available bone allows it, a certain number of implants should be placed in the posterior zones to support prostheses and avoid cantilevers (FIG 14-12), which makes it possible to extend the area of support and to guarantee a more axial transfer of the forces. For lateral and protrusive movements, the same strategies illustrated for prostheses with cantilevers should be adopted.

Removable prostheses (overdenture on single retention devices, cast bar, or milled bar)

Implant-supported removable prostheses can be more or less resilient depending on the type and extension of the implant anchorage employed. When at least four implants are strategically distributed along the arch and splinted with a milled bar, the overdenture is in every way similar to a fixed prosthesis supported exclusively by implants. This is particularly true if the prosthesis is provided with latches that can lock the device into place. In this scenario, the occlusal scheme suggested is the same as that for fixed prostheses with cantilevers.

In cases involving two to four implants onto which individual retention devices (eg, ball or ERA [Sterngold] attachments) or a cast bar with a round or teardrop-shaped section (Dolder bar) are applied, the overdenture will have combined implant and mucosa support. Because this type of prosthesis allows some degree of movement during function, a different occlusal scheme is suggested depending on whether it is opposed by natural teeth, a fixed prosthetic rehabilitation, or a complete denture. In the first case, an occlusal scheme with canine-protected occlusion or group function can be adopted. In the second, the recommended occlusal scheme is the bilateral balanced occlusion type. The latter indication chiefly derives from practical reasons (stabilizing the removable prosthesis without implant anchorage) rather than from scientific studies. Indeed, no evidence exists that this type of occlusion is better than a scheme with canine-protected occlusion, as discussed in research that collected data on retention, esthetics, and masticatory ability.[54] A correct extension of the flanges and an effective peripheral seal contribute to retention of the complete denture.

Independent of what opposes the implant-supported overdenture, static contacts should be bilateral and pointlike on the canines and on the posterior teeth, with a minimum of overbite. It is important for the guidance to be relatively flat to enable fluidity of movement.

FINAL CONSIDERATIONS

On a daily basis, the restorative dentist has occasion to observe patients with marked wear of their natural teeth who are in a state of occlusal balance and have no joint symptoms. This shows that the stomatognathic system is capable of adapting to evolving situations. In the same way, large-scale prosthetic reconstructions should be planned with an appropriate choice of materials to permit the patient or restoration (or both) to adapt during function and following wear.

In this choice, evaluation of what opposes the rehabilitation plays a determinant role. The extent of wear of artificial materials (acrylic resin, composite resin, gold alloys, ceramics) depends on the physical and chemical characteristics of the veneering material as well as on the (para)functional habits of the patient and his or her diet. Wear, which comes about with variable speeds over time, alters the occlusal balance that the clinician had initially achieved (FIG 14-13). Consequently, besides opting for comparable materials (resin opposing resin, ceramic opposing ceramic) or those with similar abrasion indices, it is recommended to carry out periodic checks to intercept and correct any occlusal discrepancies that may develop.

ACKNOWLEDGMENT

The authors wish to thank Dr Robert Faucher for his invaluable assistance in editing the chapter.

REFERENCES

1. Rangert B, Jemt T, Jörneus L. Forces and moments on Branemark implants. Int J Oral Maxillofac Implants 1989;4:241–247.
2. Adell R, Eriksson B, Lekholm U, Brånemark PI, Jemt T. Long-term follow-up study of osseointegrated implants in the treatment of totally edentulous jaws. Int J Oral Maxillofac Implants 1990;5:347–359.
3. Misch CE. Occlusal considerations for implant supported prostheses. In: Misch CE (ed). Contemporary Implant Dentistry. St Louis: Mosby, 1993.
4. Kreissl ME, Gerds T, Muche R, Heydecke G, Strub JR. Technical complications of implant-supported fixed partial dentures in partially edentulous cases after an average observation period of 5 years. Clin Oral Implants Res 2007;18:720–726.
5. Miyata T, Kobayashi Y, Araki H, Ohto T, Shin K. The influence of controlled occlusal overload on peri-implant tissue. Part 4: A histologic study in monkeys. Int J Oral Maxillofac Implants 2002;17:384–390.
6. Misch CE, Suzuki JB, Misch-Dietsh FM, Bidez MW. A positive correlation between occlusal trauma and peri-implant bone loss. Implant Dent 2005;14:108–116.
7. Tawil G. Peri-implant bone loss caused by occlusal overload: Repair of the peri-implant defect following correction of the traumatic occlusion. A case report. Int J Oral Maxillofac Implants 2008;23:153–157.
8. Tartaglia GM, Testori T, Pallavera A, Marelli B, Sforza C. Electromyographic analysis of masticatory and neck muscles in subjects with natural dentition, teeth-supported and implant-supported prosthesis. Clin Oral Implants Res 2008;19:1081–1088.
9. Frost HM. Wolff's Law and bone's structural adaptations to mechanical usage: An overview for clinicians. Angle Orthod 1994;64:175–188.
10. Stanford CM. Toward an understanding of implant occlusion and strain adaptive bone modeling and remodeling. J Prosthet Dent 1999;81:553–561.
11. Trisi P, Massei G. Biological and biomechanical basis of bone healing and osseointegration of implants in sinus graft. In: Testori T, Del Fabbro M, Weinstein R, Wallace S. Maxillary Sinus Surgery and Alternatives in Treatment. London: Quintessence, 2009:45–79.
12. Barbier L, Schepers E. Adaptive bone remodeling around oral implants under axial and nonaxial loading conditions in the dog mandible. Int J Oral Maxillofac Implants 1997;12:215–223.
13. Lekholm U, Zarb GA. Patient selection and preparation. In: Brånemark GA, Zarb G, Albrektsson T (eds). Tissue-Integrated Prostheses. Chicago: Quintessence, 1985.
14. Tada S, Stegaroiu R, Kitamura E, Miyakawa O, Kusakari H. Influence of implant design and bone quality on stress/strain distribution in bone around implants: A 3-dimensional finite element analysis. Int J Oral Maxillofac Implants 2003;18:357–368.
15. Pierrisnard L, Renouard F, Renault P, Barquins M. Influence of implant length and bicortical anchorage on implant stress distribution. Clin Implant Dent Relat Res 2003;5:254–262.
16. Garrett NR, Hasse AL, Kapur KK. Comparisons of tactile thresholds between implant-supported fixed partial dentures and removable partial dentures. Int J Prosthodont 1992;5:515–522.
17. Hämmerle CH, Wagner D, Brägger U, et al. Threshold of tactile sensitivity perceived with dental endosseous implants and natural teeth. Clin Oral Implants Res 1995;6:83–90.
18. Keller D, Hämmerle CH, Lang NP. Thresholds for tactile sensitivity perceived with dental implants remain unchanged during a healing phase of 3 months. Clin Oral Implants Res 1996;7:48–54.
19. Jacobs R, van Steenberghe D. Comparative evaluation of the oral tactile function by means of teeth or implant-supported prostheses. Clin Oral Implants Res 1991;2:75–80.

20. Mattes S, Ulrich R, Muhlbradt L. Detection times of natural teeth and endosseous implant revealed by the method of reaction time. Int J Oral Maxillofac Implants 1997;12:399–402.

21. Muhlbradt L, Mattes S, Mohlmann H, Schmid H, Ulrich R. Touch sensitivity of natural teeth and endosseous implants revealed by difference thresholds. Int J Oral Maxillofac Implants 1994;4:412–416.

22. Weinberg LA. Reduction of implant loading using a modified centric occlusal anatomy. Int J Prosthodont 1998;11:55–69.

23. Schuyler CH. Factors of occlusion applicable to restorative dentistry. J Prosthet Dent 1953;3:772–782.

24. Stallard H, Stuart CE. Concepts of occlusion. Dent Clin North Am 1963;591–606.

25. McCollum BB, Stuart CE. A Research Report: Basic Text for the Postgraduate Course in Gnathology. South Pasadena: Univ of California Scientific Press, 1955.

26. Becker CM, Kaiser DA, Schwalm C. Mandibular centricity: Centric relation. J Prosthet Dent 2000;83:158–160.

27. Wiskott HW, Belser UC. A rationale for a simplified occlusal design in restorative dentistry: Historical review and clinical guidelines. J Prosthet Dent 1995;73:169–183.

28. Weinberg LA. Reduction of implant loading using a modified centric occlusal anatomy. Int J Prosthodont 1998;11:55–69.

29. Kaukinen JA, Edge MJ, Lang BR. The influence of occlusal design on simulated masticatory forces transferred to implant-retained prostheses and supporting bone. J Prosthet Dent 1996;76:50–55.

30. Curtis DA, Sharma A, Finzen FC, Kao RT. Occlusal considerations for implant restorations in the partially edentulous patient. J Calif Dent Assoc 2000;28:771–779.

31. Morneburg TR, Pröschel PA. In vivo forces on implants influenced by occlusal scheme and food consistency. Int J Prosthodont 2003;16:481–486.

32. Brunski JB, Puleo DA, Nanci A. Biomaterials and biomechanics of oral and maxillofacial implants: Current status and future developments. Int J Oral Maxillofac Implants 2000;15:15–46.

33. Testori T, Bianchi F, Del Fabbro M, Szmukler-Moncler S, Francetti L, Weinstein RL. Immediate non-occlusal loading vs. early loading in partially edentulous patients. Pract Proced Aesthet Dent 2003;15:787–794.

34. Testori T, Galli F, Capelli M, Zuffetti F, Esposito M. Immediate nonocclusal versus early loading of dental implants in partially edentulous patients: 1-year results from a multicenter, randomized controlled clinical trial. Int J Oral Maxillofac Implants 2007;22:815–822.

35. Schincaglia GP, Marzola R, Fazi G, Scapoli C, Scotti R. Replacement of mandibular molars with single-unit restorations supported by wide-body implants: Immediate versus delayed loading. A randomized controlled study. Int J Oral Maxillofac Implants 2008;23:474–480.

36. Lundgren D, Laurell L. Biomechanical aspects of fixed bridgework supported by natural teeth and endosseous implants. Periodontol 2000 1994;4:23–40.

37. Renouard F, Nisand D. Impact of implant length and diameter on survival rates. Clin Oral Implants Res 2006;17(suppl 2):35–51.

38. Tawil G, Aboujaoude N, Younan R. Influence of prosthetic parameters on the survival and complication rates of short implants. Int J Oral Maxillofac Implants 2006;21:275–282.

39. Blanes RS. To what extent does the crown-implant ratio affect the survival and complications of implant-supported reconstructions? A systematic review. Clin Oral Implants Res 2009;20:67–72.

40. Lang NP, Pjetursson BE, Tan K, Brägger U, Egger M, Zwahlen M. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years. II. Combined tooth and implant-supported FPDs. Clin Oral Implants Res 2004;15:643–653.

41. Franchi I, Bortolini S, Natali A, Franchi M, Consolo U. Tooth-implant connection and tooth intrusion: Biomechanical considerations. Ital J Osseointegration 2004;3:131–135.

42. Cordaro L, Ercoli C, Rossini C, Torsello F, Feng C. Retrospective evaluation of complete-arch fixed partial dentures connecting teeth and implant abutments in patients with normal and reduced periodontal support. J Prosthet Dent 2005;94:313–320.

43. Nickenig HJ, Schafer C, Spiekermann H. Survival and complications rates of combined tooth-implant-supported fixed partial dentures. Clin Oral Implants Res 2006;17:506–511.

44. McAlarney ME, Stavropoulos DN. Determination of cantilever length-anterior-posterior spread ratio assuming failure criteria to be the compromise of the prosthesis retaining screw-prosthesis joint. Int J Oral Maxillofac Implants 1996;11:331–339.

45. Mericske-Stern RD, Assal P, Mericske E, Burgin W. Occlusal force and oral tactile sensibility measured in partially edentulous patients with ITI implants. Int J Oral Maxillofac Implants 1995;10:345–353.

46. Kim Y, Oh TJ, Misch CE, Wang HL. Occlusal considerations in implant therapy: Clinical guidelines with biomechanical rationale. Clin Oral Implants Res 2005;16:26–35.

47. Shackleton JL, Carr L, Slabbert JC, Becker PJ. Survival of fixed implant-supported prostheses related to cantilever lengths. J Prosthet Dent 1994;71:23–26.

48. Brånemark PI, Svensson B, van Steenberghe D. Ten-year survival rates of fixed prostheses on four or six implants ad modum Brånemark in full edentulism. Clin Oral Implants Res 1995;6:227–231.

49. Taylor TD. Fixed implant rehabilitation for the edentulous maxilla. Int J Oral Maxillofac Implants 1991;6:329–337.

50. Rodriguez AM, Aquilino SA, Lund PS. Cantilever and implant biomechanics: A review of the literature, Part 2. J Prosthodont 1994;3:114–118.

51. Lundgren D, Falk H, Laurell L. Influence of number and distribution of occlusal cantilever contacts on closing and chewing forces in dentitions with implant-supported fixed prostheses occluding with complete dentures. Int J Oral Maxillofac Implants 1989;4:277–283.

52. Duyck J, Van Oosterwyck H, Vander Sloten J, De Cooman M, Puers R, Naert I. Magnitude and distribution of occlusal forces on oral implants supporting fixed prostheses: An in vivo study. Clin Oral Implants Res 2000;11:465–475.

53. Lundgren D, Laurell L. Occlusal forces in prosthetically restored dentitions: A methodological study. J Oral Rehabil 1984;11:29–37.

54. Peroz I, Leuenberg A, Haustein I, Lange KP. Comparison between balanced occlusion and canine guidance in complete denture wearers. A clinical, randomized trial. Quintessence Int 2003;34:607–612.