Reduction of Implant Loading Using a Modified Centric Occlusal Anatomy

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Purpose: This paper focuses on the derivation of implant loading forces as influenced by occlusal anatomy. Vertical occlusal forces on cusp inclines produce resultant lines of force that result in lateral rather than vertical forces to the supporting bone. **Materials and Methods:** An analysis of resultant lines of force with different impacting occlusal surfaces was illustrated. Methods were suggested to decrease implant loading by reducing cusp inclines, utilization of cross occlusion, and the modification of occlusal anatomy to provide a continuous 1.5-mm flat fossae, rather than the line angles of the usual cuspal anatomy. The relationship of incisal guidance to the cusp inclines on the adjustable articulator were reviewed. Modification of the incisal pin and articulator settings were suggested to produce a 1.5-mm fossae throughout the prosthesis. Practical laboratory and intraoral occlusal adjustment techniques were suggested to provide a modified centric occlusal anatomy to help decrease implant loading. **Results:** Clinical examples were shown to verify the accuracy of the modified settings on the semi-adjustable articulator and the resultant modified occlusal anatomy. **Conclusion:** Implant loading can be reduced by modifying the location of the impact area and the occlusal anatomy. Simple modification of the incisal pin and articulator settings can be used to produce a 1.5-mm flat fossae, which results in more vertical forces to the supporting bone. The same procedures are used to reduce cusp inclinations, which effectively lessens the torque exerted on the prosthesis, implant, and bone. A combination of all these factors can prevent implant overload.
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After stage-two surgery, the highest incidence of failure has been attributed to implant overload.[1] However, the biomechanical factors cited in the literature that contribute to implant overload, such as bone type,[2] cuspal inclination,[3] horizontal offset,[3,4] maxillary compared to mandibular arch,[4] the inclusion of natural teeth within the prosthesis,[5] and occlusal anatomy,[3–9] are superimposed on physiologic variations. This prevents the isolation of a single etiologic factor in vivo, making scientific proof virtually impossible. In the absence of such scientific proof, the study and clinical application of biomechanical factors remains controversial.

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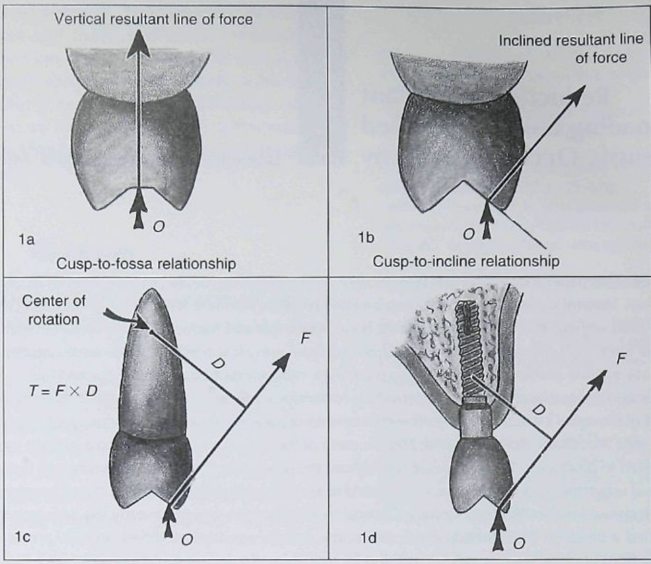
It is within this framework that the author presents his opinion and rationale that the location and character of the impacting tooth surfaces affects the resultant force distribution to the prosthesis, implant, and supporting bone, and which thereby influences success and failure. The purpose of this article is to suggest, where clinically feasible, the modification of centric occlusal anatomy[3–5] to aid lateral force reduction using a laboratory and clinical adjustment procedure[6–8] as a practical means of reducing occlusal loading.

Development of Loading Forces

The application of muscle force initiates the biomechanical loading process; however, there are many factors that alter the magnitude and quality of the force ultimately delivered to the implant and surrounding bone. One of the most frequently overlooked factors is the location of the applied load in

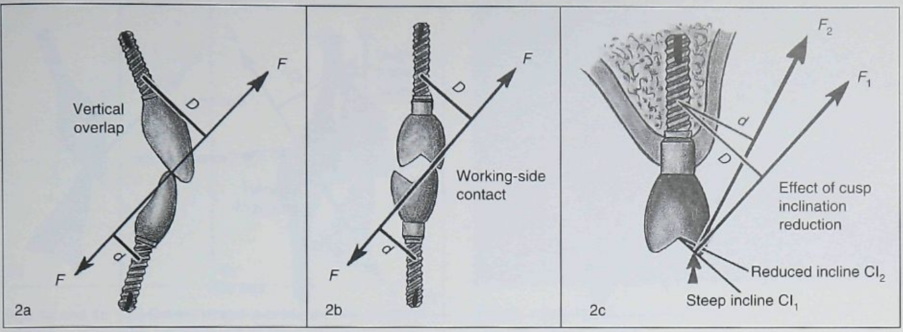


Figs 1a to 1d (a) An occlusal force *(O)* on a horizontal fossa produces a vertical line of force. (b) An occlusal force *(O)* on a cusp incline produces an inclined resultant line of force. (c) Torque is the force *(F)* times the perpendicular distance *(D)* from the center of rotation of the tooth located in the apical third. (d) The maximum loading on an implant is in the area of the third screw thread, from which the distance *(D)* is measured to the resultant line of force *(F)*.

the dental arch, because the force delivered by the musculature is approximately four times greater in the posterior part of the mouth than in the anterior.[9]

During mastication the teeth seldom impact,[10] although during deglutition direct occlusal contact transmits forces to the supporting bone. It should be noted that when the bolus reaches its limit of elasticity, it distributes forces through the occluding surfaces as if occlusal contact has occurred.[3,11] The preceding concept is moot because nonmasticatory loading from clenching and/or bruxism distributes force to the supporting bone through direct occlusal contact. The controversial question explored here is the *effect* of the occlusal anatomy on the character of the resulting force transmission to the implant and supporting bone.

When the muscles of mastication occlude teeth, there are several interrelated factors that determine the subsequent direction and magnitude of the force distributed to the supporting bone. The anatomy of the occluding surfaces, or impact area, determines the direction of the resultant line of force, while the location of that resultant line of force, relative to the implant or natural tooth root and the supporting bone, will determine the character (effect) of the applied load. In its simplest form, when a cusp occludes with a flat fossa, the resultant line of force passes vertically close to or in line with the supporting bone (Fig 1a). However, when a cusp impacts an incline, the resultant line of force passes obliquely away from the supporting bone (Fig 1b). This creates a lateral force component that has been thought to be more deleterious to the supporting bone than vertical loading.[12] If these principles are accepted as a reasonable working hypothesis, then the occlusal anatomy can be modified in the laboratory to reduce and redirect the pattern of force distribution resulting from masticatory and nonmasticatory function. This concept can be applied to implant- or tooth-supported prostheses.



Figs 2a to 2c (a) With a vertical overlap anteriorly, the distance *(D)* is greater on the maxillary implant than on the mandibular implant *(d)*; therefore, the torque is similarly disproportional. (b) With working-side contact on the maxillary buccal cusp incline, there is more torque on the maxillary implant than on the mandibular implant, as reflected by the disproportional distances *(D)* and *(d)* from the resultant line of force *(F)*. (c) A steep cusp incline *(CI_1)* produces a resultant line of force *(F_1)* at a great distance *(D)* from the implant, which results in exaggerated torque. Conversely, a reduced cusp incline *(CI_2)* produces a resultant line of force *(F_2)* that is closer *(d)* to the implant, and thus reduces the torque.

*Production of Torque**

The measurement of torque in a natural tooth is the force *(F)* times the perpendicular distance *(D)* from the center of rotation (Fig 1c) in the apical third.[11] However, the relative stiffness of titanium and alveolar bone (compared to the flexion permitted by the periodontal ligament) concentrates the maximum loading in the area of the third screw thread of the implant[13] (Fig 1d). For convenience, this maximum loading area will be used in all the illustrations. Three-dimensional finite element stress analysis[13,14] also indicates that inclined loading applied to the implant (as in Fig 1d) results in a concentration of loading to the crestal bone rather than distribution along the entire implant surface.

There is usually more torque produced in the maxillary arch than in the mandibular arch.[4] For example, a vertical overlap in the anterior of the mouth produces more torque in the maxilla than in the mandible because the distance *(D)* from the resultant line of force is greater than the distance in the mandible (*d*, Fig 2a). Posteriorly, lingual cuspal articulation on the working-side occlusion is rarely produced in restored occlusion because of the limited use of fully adjustable articulators. When this type of occlusion occurs, there is more torque in the maxillary arch than in the mandibular arch because the resultant line of force *(D)* falls at a greater distance from the supporting bone[4] (*d*, Fig 2b).

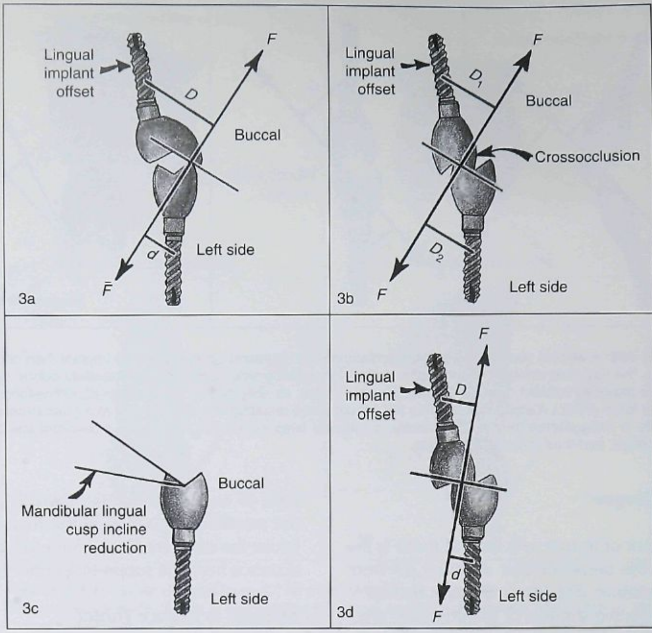
Methods to Reduce Torque

Reduction of Cusp Inclination. One of the most significant factors in the production of torque is cusp inclination,[3,4] which can be reduced in tooth-supported as well as implant-supported prostheses. For example, with a reduction in maxillary cusp inclination *(CI_2)*, the resultant line of force *(F_2)* falls closer to the implant (and bone) than when there is a more acute cuspal inclination (*F_1*, Fig 2c).

Modification of Location. With natural teeth the location of the occlusal surface may be dictated by pulpal anatomy. There is much more flexibility in the location of the occlusal surface with an implant-supported prosthesis. For example, if a posterior maxillary implant is offset too far lingually (regardless of the cusp inclination), the resultant line of force passes at a greater distance *(D)* from the maxillary implant and supporting bone (Fig 3a) than it does from the mandibular implant (*d*, Fig 3a).

Torque can be reduced on the maxillary implant by placing the prosthesis in crossocclusion, which decreases the distance (D_1) of the resultant line of force from the implant and supporting bone (Fig 3b).[3] However, crossocclusion can inadvertently reverse the situation and increase the torque on the mandibular implant (or tooth) by increasing the distance *(D_2)* of the resultant line of force from the implant, and thus increase the torque (Fig 3b). This

*(Author's note) Some engineers prefer the term "moment" rather than "torque," although the terms are generally synonymous and measured as force times the perpendicular distance from the center of rotation. Torque is used in the text because it is thought to be more clearly understood by dentists, and is associated with a lateral force component, while moment may obfuscate rather than clarify an already complicated discussion.



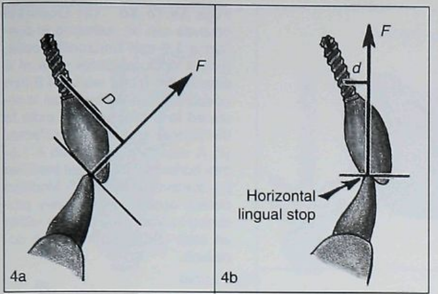
Figs 3a to 3d (a) When a maxillary implant has an exaggerated lingual offset, the resultant line of force passes at a greater distance *(D)* from the maxillary implant than it does from the mandibular implant *(d)*. (b) When the maxillary restoration is placed in crossocclusion, the distance (D_1) between the maxillary implant and the resultant line of force *(F)* decreases. However, the distance (D_2) between the resultant line of force and the mandibular implant increases. (c) Elevated torque on the mandibular implant can be prevented by reducing the mandibular lingual cusp incline before the maxillary restoration is constructed. (d) When restored, the distances in both arches *(D, d)* are reduced, and torque is effectively reduced.

can be prevented by reducing the mandibular lingual cusp inclination (Fig 3c) before the maxillary arch is restored. Thus, the distances *(D, d)* between the resultant line of force and the implants and supporting bone are reduced in both arches (Fig 3d), which effectively reduces torque.

Modification of Anterior Anatomy. When there is an anterior vertical overlap, the resultant line of force passes at an exaggerated distance *(D)* from the implant and supporting bone (Fig 4a), producing considerable torque.[3,11] The lingual surface of the maxillary restoration can be modified to provide a horizontal lingual "stop" for the mandibular incisor (Fig 4b). The resultant line of force *(F)* falls closer to the implant and supporting bone, producing less torque (*d*, Fig 4b). This design helps prevent screw breakage. It is suggested that this anatomy be incorporated into provisional restorations whenever possible to facilitate patient tactile and speech adaptation. Figure 4c illustrates recontoured maxillary incisor lingual surfaces on a tooth-supported fixed prosthesis with typical posterior anatomy.

Modification of Posterior Occlusal Anatomy to Reduce Torque

With typical posterior occlusal anatomy, buccal and lingual cusp inclines meet in an occlusal



Figs 4a and 4b (a) Severe torque is produced with a vertical anterior overlap. The resultant line of force *(F)* passes at an exaggerated distance *(D)* from the implant. (b) A horizontal lingual stop on the maxillary restoration produces a more vertical line of force, which falls closer *(d)* to the implant and reduces torque.

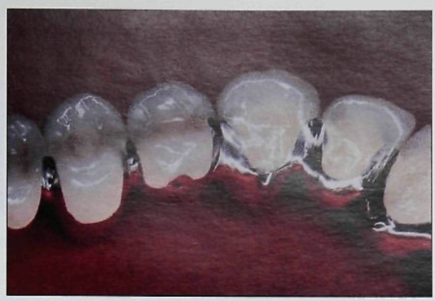


Fig 4c Recontoured maxillary incisor lingual surfaces with typical posterior anatomy.

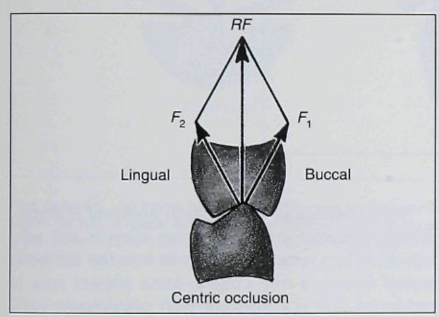


Fig 4d Hypothetically, typical cuspal anatomy in a cusp-to-fossa relationship produces buccal *(F_1)* and lingual *(F_2)* component lines of force that combine to form a vertical resultant line of force *(RF)*.

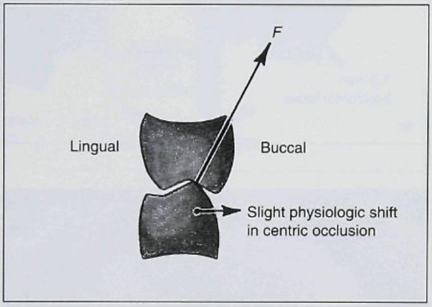
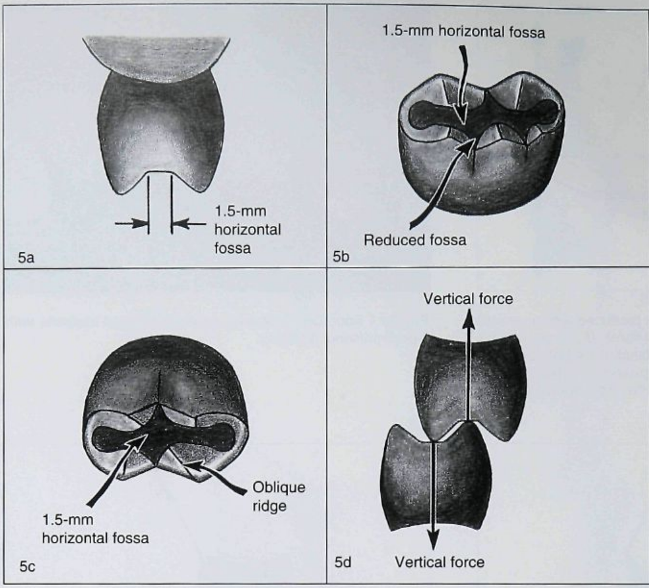


Fig 4e Physiologic variation causes individual cusp incline contact, which produces an inclined resultant line of force *(F)*.

groove that provides no flat horizontal surface. From a functional standpoint, it is a misnomer to call this groove a fossa because it is formed by two or more inclined planes without a flat (horizontal) surface. Conventional wisdom accepts that a posterior "cusp-to-fossa" occlusal relationship is biomechanically favorable. The hypothesis is that buccal *(F_1)* and lingual *(F_2)* component lines of force (generated by the cusp incline surfaces) produce a vertical resultant line of force (*RF,* Fig 4d) that is biomechanically favorable.

This is only correct theoretically, because such repeatably precise fit is unattainable clinically because occlusal contact in centric relation has been shown to be a *small area* (in the range of ± 0.4 mm) rather than an immutable point.[15–18] Centric relation has been demonstrated to vary over a period of time,[15] methods of recording,[16] and variations in muscular conditioning.[17,18] As a result, the slightest physiologic variation in position will result in only one incline contact producing a laterally inclined resultant line of force (*F,* Fig 4e) (buccal cusp incline contact illustrated). In the author's opinion, to be more compatible with physiologic variation as described above,[15–18] a modified centric occlusal anatomy should be used to provide a true horizontal fossa rather than line angles (or grooves).



Figs 5a to 5d (a) Occlusal grooves can be reshaped to contain a 1.5-mm horizontal fossa. (b) An occlusobuccal view of a mandibular molar with a 1.5-mm horizontal fossa. The fossa is reduced to a groove as it exits to the buccal and lingual surfaces. (c) A maxillary molar with a 1.5-mm horizontal fossa that modifies the transverse ridge. (d) Modified centric occlusion effectively produces vertical lines of force within an area of contact in centric occlusion.

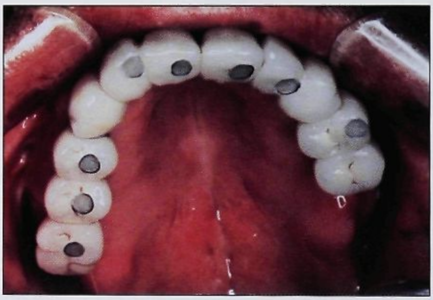


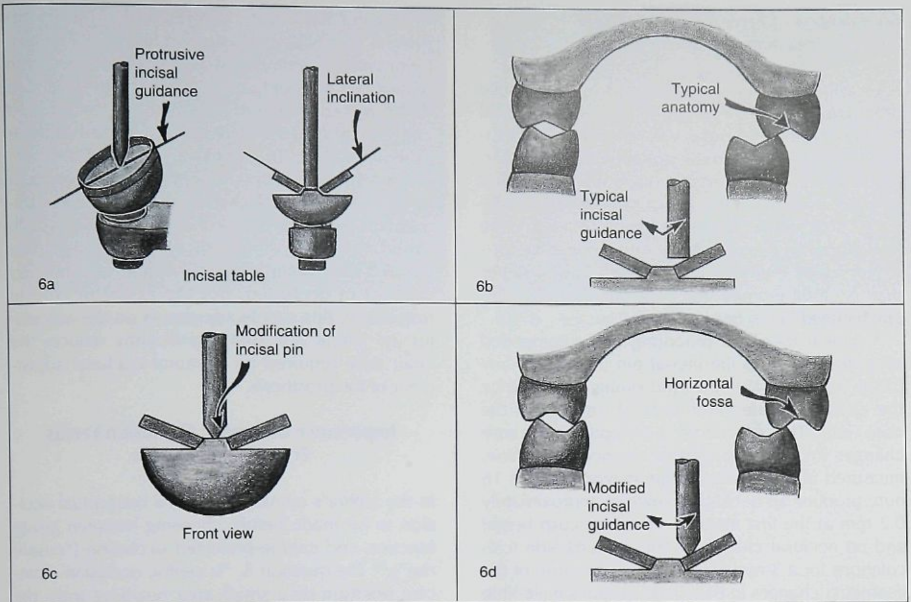
Fig 5e Clinical example of a maxillary implant-supported prosthesis with a modified centric occlusal anatomy.

It is suggested that the occlusal line angles and grooves should be reshaped to contain a 1.5-mm horizontal fossa (Fig 5a). Figure 5b illustrates an occlusobuccal view of the modified horizontal fossae on a mandibular molar that replaces the standard grooves. The fossa is reduced to a standard groove as it exits on the buccal and lingual surfaces to prevent unesthetic, sharp edges. The maxillary molar occlusal anatomy is modified in a similar way, eliminating the oblique ridge, which is flattened in the "central fossa" area to maintain a constant horizontal fossa across the entire occlusal surface (Fig 5c).

The advantage of this occlusal anatomy is immediately negated if the opposing cusp is not narrowed. When narrowed cusps fit into the flat horizontal fossae, a true cusp-to-fossa impact area is produced that is consistent with physiologic variability.[15–18] This effectively produces vertical lines of force within an area of contact in centric occlusion (Fig 5d). A clinical example of a modified centric occlusal anatomy for a maxillary implant-supported prosthesis is shown in Fig 5e. This figure should be contrasted to typical occlusal anatomy in which the slightest physiologic variation from the exact centric occlusal position can produce a laterally inclined resultant line of force (see Fig 4e).

The concept of flat horizontal fossae rather than sharp line angles and grooves is certainly not new. Mann and Pankey,[19] suggested using a "long centric" occlusal design that contained a fossa that extended from the point of centric contact into all eccentric excursions.

The long centric occlusal design was created by a technique using an intraoral functionally generated path[19] that did not gain extensive use because of inherent technical difficulties and the limitations of space associated with natural teeth. However, with implant-supported prostheses, these spacial requirements are reduced, and a more biomechanically advantageous occlusal



Figs 6a to 6d (a) Incisal table is rotated to provide protrusive guidance *(left)*, while the lateral guide planes provide lateral guidance *(right)*. (b) With a typical incisal pin, lateral movement initiates immediate inclination; thus, the typical cuspal anatomy (central groove) is produced. (c) Front view. The incisal pin is tapered approximately 1 mm on both sides. (d) Bilateral movement of the modified incisal pin on the typical incisal table produces a modified centric occlusal anatomy with a 1.5-mm horizontal fossa.

scheme could be used, if a simple practical laboratory technique were available. The technique suggested here offers a clinical alternative that uses a simple semiadjustable articulator with a modification of the standard incisal pin. Other articulators and procedures can be used to obtain similar results. Intraoral occlusal adjustment is required, no matter what occlusal anatomy or technique is followed.

Modification of Typical Incisal Pin

A typical Hanau (Teledyne Waterpik) incisal table is rotated to provide protrusive guidance while the lateral adjustable guide planes provide lateral inclination (Fig 6a). The incisal pin itself is usually flat (from the front view), and as it moves on the incisal table it combines with the condylar guidances to generate the standard buccal and lingual cusp inclines that join in a central groove (Fig 6b) (as previously described, this is a line angle).[6,20]

The incisal pin can be simply modified to produce a horizontal 1.5-mm fossa on any adjustable articulator. The portion of the incisal pin that touches the plane can be beveled approximately 1 mm on both sides as observed from the frontal view (Fig 6c). After this reduction in width, as the incisal pin is moved laterally it remains on the flat plane until it contacts the angulated lateral guide planes of the table (Fig 6d). During this portion of lateral movement (ie, on the flat plane), a corresponding horizontal fossa is created in the posterior occlusion (Fig 6d). With this simple modification of the incisal pin, bilateral lateral movements on the articulator produce a truly horizontal central fossa of approximately 1.5 mm in width (Fig 6d). It should be noted that the incisal pin must be kept in the same orientation as illustrated in Fig 6c. Increasing the width of the bevel on the incisal pin or overgrinding it to a point will excessively widen the horizontal fossa. A laboratory trial will establish the desired fossae dimension.

Modification of Typical Semiadjustable Articulator Settings

Most clinicians do not use a completely adjustable articulator[20] with the required three-dimensional records. Furthermore, the vast majority of restorations are completed on a straight-line articulator, and when a semiadjustable instrument is used, it rarely is used to its maximum potential. It is suggested that semiadjustable instruments should be reevaluated as a practical means of producing horizontal fossae (with vertical resultant forces) rather than occlusal grooves that most often produce lateral inclined forces (torque).

A typical face-bow mounting is recommended using the notch on the incisal pin (Hanau) or any of the accepted anterior-third points of reference the clinician prefers (infraorbital rim, ala of the nose, etc). This procedure is acceptable because changes in vertical height of the occlusal plane, measured at the incisors in the magnitude of ± 16 mm, produce an occlusal change of approximately 0.2 mm at the first molar nonworking cusp height and no occlusal change on the working side (calculations for a 3-mm cusp width).[20] Because of the geometry, changes in patient dimensions have little tangible effect on the nonworking-side cusp inclines, and no effect on the working-side cusp inclines when the face-bow is elevated or lowered as described.

Semiadjustable articulators use protrusive check bite records to establish protrusive condylar inclination. However, since these instruments do not usually have an adjustable intercondylar distance, lateral check bite records would be difficult to transfer accurately.[20] In lieu of lateral records, the Bennett angle (medial angulation of the nonworking [balancing] condyle) has been calculated by formula (Hanau)[20–23] without verification of its derivation. This procedure on the articulator is the mechanism that provides the lateral Bennett movement of the working condyle. However, in the author's experience, the working posterior cusp inclinations that are produced with this method are usually too flat (negative error).[23] This negative error can be corrected by eliminating the lateral Bennett movement on the articulator.[23]

The relationship between the extreme guidances (condylar guidances and incisal guidance) and cusp inclination on diversified articulators has been evaluated mathematically.[20] On the basis of these mathematical calculations and long clinical experience, the author recommends modification of the typical semiadjustable articulator techniques to correct their deficiencies and provide improved, practical, cost-effective results.[23] The posterior working-side negative error, associated with typical settings containing a lateral side shift, can be corrected by simply eliminating the Bennett angle on the instrument (rotating the condylar posts laterally to 0). This will increase the posterior working cusp inclines. For example, Fig 7a illustrates the completed restorations on the instrument in working-side relationship. Figure 7b shows the restorations intraorally in the same working-side relationship. No matter the preferred concept of occlusion, nor the extent or type of restoration, this simple adjustment on the articulator (no lateral side shift) significantly reduces the chair time required for intraoral occlusal adjustment of the prosthesis.

Importance of Centric Occlusion Versus Eccentric Occlusion

In the author's opinion, there is a conceptual decision to be made before choosing between group function and canine-protected occlusion ("cuspid rise").[24] The question is, "Is centric occlusion a precise position or a small area resulting from the physiologic variability of centric relation, as described in the literature?"[15–18] If a clinician believes centric occlusal contact should be a nonvariable, precisely replicable point, then a canine-protected occlusion might logically obviate the need for a posterior scheme of occlusion designed to limit lateral forces. One need only be concerned about the patient's clenching or bruxism.

However, if a clinician agrees with the research that describes centric relation as having physiologic variability influenced by muscle tone, head position, time of day or over several days, and muscle conditioning, then centric occlusal contact should not be anatomically locked into one precise position. Centric occlusal contact should provide a *small area* of simultaneous harmonious contact, regardless of the occlusal scheme used for eccentric contact. The size of that area and the clinical methods to obtain it are influenced by the occlusal space available, whether a tooth-supported or an implant-supported prosthesis is planned, and the preference and skill of the clinician.

In the author's opinion, the choice between group function or canine-protected occlusion depends on specific individual prosthodontic factors as well as the clinician's preference and is far less important than the type of centric occlusal contact provided for the patient.

Fig 7a Working-side occlusal relationship on the articulator.

Fig 7b Intraoral view of the working-side occlusal relationship.

Laboratory Articulator Concepts and Technique

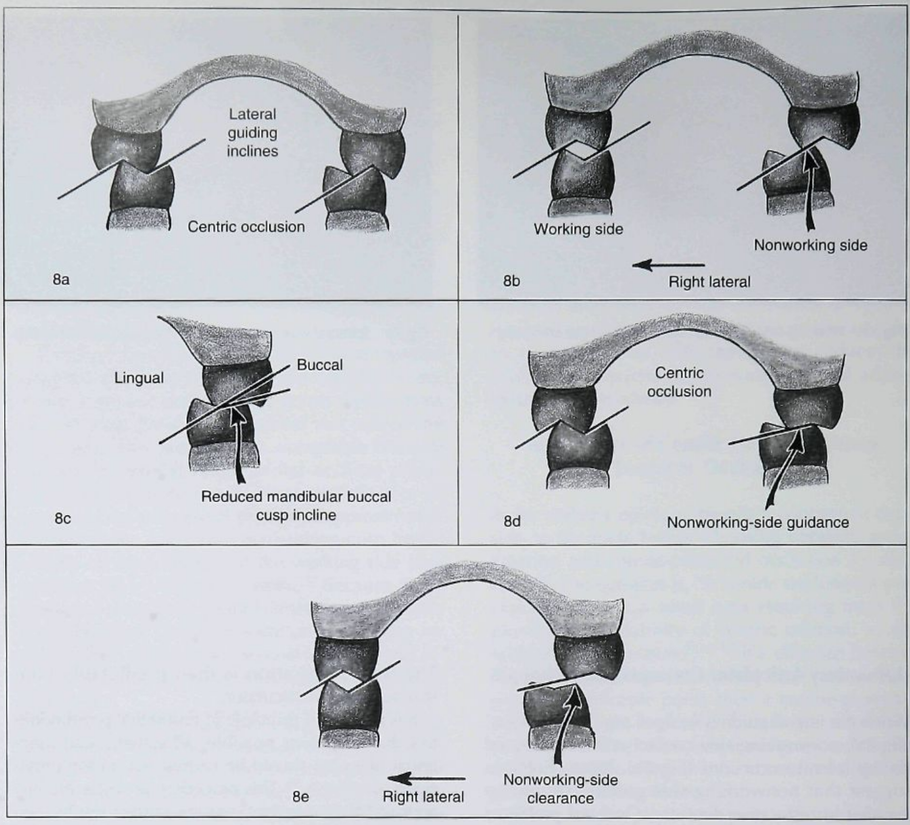
When the lateral guiding inclines are "harmonious" (Fig 8a), nonworking-side contact will be produced during lateral excursions (Fig 8b). Most clinicians suggest that nonworking-side contact should be avoided in restorative dentistry. Occlusal problems can be avoided by simple preplanning and preventative correction.

Nonworking-side contact can be avoided by correction of the opposing occlusion before restorative procedures are instituted. This procedure will also prevent the possible loss of centric occlusal contact as well as unnecessary occlusal disharmony. For example, prevention of nonworking-side contact in the final maxillary implant-supported restoration (on the patient's left side as shown in Fig 8b) is accomplished by reducing the opposing mandibular buccal cusp incline (Fig 8c) before restorative procedures are instituted on the opposing (maxillary) arch. The maxillary implant-supported provisional restoration is fabricated against the reduced mandibular buccal cusp incline to provide good centric contact (Fig 8d). Nonworking-side freedom is confirmed when the patient moves into right lateral excursion (Fig 8e). The final restoration is then predictably constructed on the articulator.

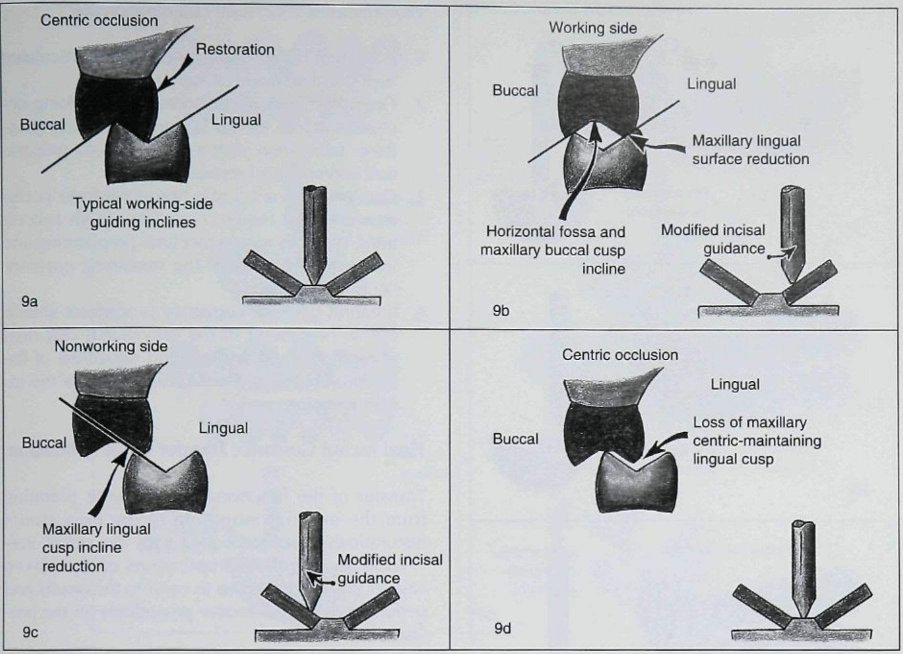
It is a cardinal principle in restorative prosthodontics that whenever possible, all esthetic and functional planning should be carried out on the provisional prosthesis.[25] This procedure provides esthetic approval by the patient, ensures correct results, and provides an important therapeutic trial. It also provides an opportunity for correction of the planned incisal guidance in the provisional prosthesis. When the provisional prosthesis is acceptable, it also provides a method of transference of the esthetics and corrected incisal guidance to the articulator for the final prosthesis.[23,25]

Practical Technique for Obtaining 1.5-mm Occlusal Fossae in the Maxillary Arch

The guiding cusp inclines for lateral excursions are well understood as shown in Fig 8a. However, if a 1.5-mm fossa is planned for the maxillary arch opposing unrestored standard occlusal anatomy in the mandibular arch, the modified incisal guidance (as previously described in Fig 6d), will remove centric contact on the maxillary lingual cusps. The mechanism of this process is as follows:



Figs 8a to 8e (a) Typical lateral guiding inclines are shown in centric occlusion. (b) When the lateral guiding inclines are "harmonious," nonworking-side contact is produced. (c) Opposing mandibular buccal cusp incline is reduced before the maxillary restoration is fabricated. (d) Maxillary left restoration is restored to the corrected mandibular occlusal anatomy, which reduces the nonworking-side guidance. (e) During right lateral movement, nonworking-side clearance is produced.



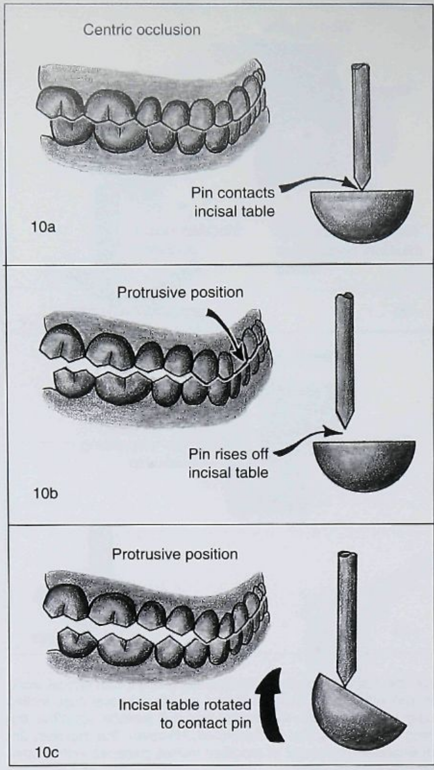
Figs 9a to 9d (a) Maxillary restoration is shown in centric occlusion on the articulator before occlusal adjustment with typical working-side guiding inclines. (b) When a modified incisal guidance is used, half of the horizontal fossa and maxillary buccal cusp incline is produced during working-side movements. The mandibular lingual cusp incline reduces the maxillary lingual surface. (c) When the articulator is moved in the opposite nonworking excursion, the remaining half of the fossa is completed. However, the maxillary lingual cusp incline is reduced by the mandibular buccal cusp incline. (d) Bilateral movement of modified incisal guidance with a standard mandibular anatomy causes the loss of the maxillary lingual centric maintaining cusp.

The unadjusted maxillary restoration is shown in centric occlusion with the incisal pin in the center of the incisal table (Fig 9a). As the incisal pin moves in lateral excursion, first along a flat path to produce the horizontal fossa (maxillary fossa, Fig 9b), and then up the incline (incisal pin movement, Fig 9b), the buccal cusp incline will be formed. However, the mandibular occlusal anatomy has no horizontal fossa. As a result, during working-side movements the lingual cusp incline will reduce the lingual slope of the maxillary lingual cusp (Fig 9b). When the articulator is moved in the opposite nonworking direction (Fig 9c), the mandibular buccal cusp incline will similarly reduce the maxillary lingual cusp incline in harmony with the incisal pin movement.

This bilateral movement removes the maxillary lingual cusp from centric contact when the incisal pin returns to the centric position (Fig 9d). This description illustrates why a modified centric occlusion with 1.5-mm fossae must be provided for the entire mouth, regardless of the extent of the restoration itself.

Modification of Opposing Occlusion (Fossae Preparation) Before Restorative Procedures

Most restorative dentists are accustomed to reducing an opposing overerupted tooth before initiating restorative dentistry to produce an esthetic plane of occlusion. In the simplest terms, the same principle is applied to occlusal modification. As previously discussed, a standard anatomy cannot be articulated with a prosthesis containing a modified occlusal anatomy with 1.5-mm fossae without interfering with the centric occlusion-maintaining cusps (Figs 9a to 9d). However, loss of centric occlusal contact can be prevented by preparing a preoperative 1.5-mm fossa in all of the remaining unrestored



Figs 10a to 10c Transfer of protrusive incisal guidance: (a) Step I. Casts are in centric occlusion and the incisal pin contacts the incisal table. (b) Step II. Casts are placed in protrusive position. Pin rises off the incisal table. (c) Step III. Incisal table is rotated to contact the pin, and the protrusive incisal guidance to the instrument is thus transferred.

teeth (or restoring the teeth with Class I restorations). Occlusal coordination within both arches is essential.

It should be noted that most patients requiring implant-supported prostheses (or extensive tooth-supported prostheses), already have many restorations that can be reshaped to coordinate with a modified centric occlusal anatomy containing 1.5-mm fossae. For patients with extensive enamel surfaces that would require correction, the restorative dentist can make the decision whether additional Class I restorations are justified to gain the advantages of reduced implant loading.

The principles of occlusal coordination are:

1. A 1.5-mm horizontal fossa cannot be articulated with standard occlusal anatomy.
2. Central grooves of the unrestored opposing occlusal surfaces should be modified before prosthesis fabrication with a 1.5-mm fossa preparation and/or Class I restorations.
3. Conversion to a 1.5-mm horizontal fossa occlusion does not require complete mouth restorations, but does require occlusal preplanning and the reshaping of all of the remaining posterior occlusal surfaces.
4. Intraoral occlusal corrective procedures should follow placement of the provisional and final restorations, and are required regardless of the occlusal anatomy, the technique, and/or the instrumentation used.

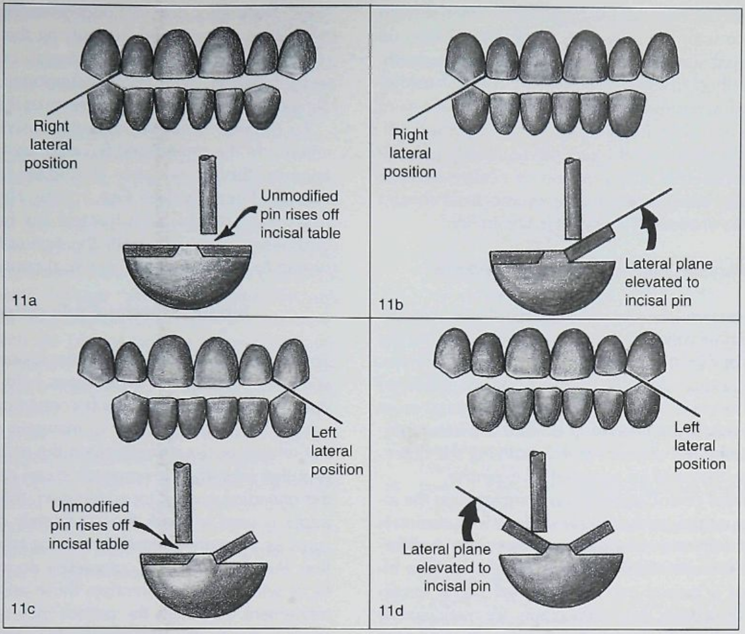
Final Incisal Guidance Transfer to the Articulator

Transfer of the functional and esthetic planning from the original mounting to the provisional restorations is accomplished with the aid of irreversible hydrocolloid impressions of the waxed casts.[25] It is advantageous to confirm the results and perform intraoral corrective procedures on the provisional restorations.

A cast of the maxillary provisional restorations is obtained in addition to the final casts. A facebow mounting is used to transfer the final maxillary cast to the articulator, and the mandibular cast is positioned with the centric record of preference. The protrusive interarch registration is transferred to the articulator. The maxillary final cast is removed from the articulator and the stone cast of the intraoral provisional restoration is hand-articulated with the mandibular cast and luted to the articulator (Fig 10a).

An unmodified incisal pin is positioned and should touch the incisal table with the casts in centric occlusion (Fig 10a). The casts are placed in protrusive position (Fig 10b), which causes the incisal pin to rise off the plane in proportion to the degree of vertical overlap (Fig 10b).[23] The incisal table is rotated until it touches the elevated incisal pin (Fig 10c).

The casts are moved into (right) lateral position and luted (Fig 11a). The pin rises off the plane relative to the lateral inclination (Fig 11a). The lateral guide plane is elevated until it touches the incisal pin, and thus transfers the right lateral incisal guidance (Fig 11b). The procedure is repeated for the left lateral incisal guidance (Figs 11c and 11d).



Figs 11a to 11d Transfer of lateral incisal guidance: (a) Step I. The casts are placed in right lateral position causing the incisal pin to rise off the plane. (Illustrations are diagrammatic for clarity). (b) Step II. The lateral plane is elevated to the incisal pin, transferring right lateral incisal guidance. (c) Step III. The casts are placed in left lateral position causing the incisal pin to rise off the plane. (d) Step IV. The lateral plane is elevated to the incisal pin, transferring left lateral incisal guidance.

Fabrication and Occlusal Adjustment on the Instrument

The typical incisal pin is removed and is replaced with the modified incisal pin as described in Fig 6c. The condylar mechanism is used as previously described (see Fig 7a).[22] The technician fabricates the prosthesis with attention to the following details: *(1)* Rounded or flattened centric occlusion–maintaining cusps should be avoided; *(2)* narrow cusps should fit into the middle of the fossae; *(3)* central grooves should be eliminated and a modified occlusion containing 1.5-mm horizontal fossae provided; *(4)* centric occlusion should be provided with narrow cusps fitting into the central portion of the 1.5-mm horizontal fossae; *(5)* the occlusion should be corrected on the instrument (procedure to follow) so that lateral movements can be made with the modified incisal pin remaining on the plane; and *(6)* the absence of nonworking-side occlusal interference should be confirmed.

The principles of occlusal adjustment (following the BULL rule) have been well established.[7,8] Evenly distributed centric occlusal contact can be confirmed with the aid of 0.0005-inch mylar tape (Artus Occlusion Strips, Patterson Dental) and very thin articulator paper (Bausch Articulating Paper, Pulpdent). The importance of avoiding flat or rounded centric-maintaining cusps should be emphasized. The narrow cusp contour should be established first, and then the fossa should be corrected with constant attention to the objective of a narrow cusp functioning on a 1.5-mm horizontal fossa. This means the cusp should make a small discrete centric occlusal marking in the middle of the fossa. The cusps should have an area of freedom of lateral movement on a horizontal fossae.

The incisal edges of the mandibular anterior teeth articulate with a narrow horizontal lingual stop on the lingual surfaces of the maxillary anterior teeth, as described in Fig 4b. However, without further occlusal adjustment, anteroposterior freedom of movement on a horizontal plane is prevented, which, in effect, would lock the occlusion into the most retruded border position of centric relation and defeat the concept that centric occlusal contact is an area caused by physiologic variability.

Laboratory Occlusal Adjustment Procedures

Skilled technicians can adjust standard lateral movements on an articulator and maintain contact of the incisal pin on the plane during lateral movements. The principles are exactly the same for modified centric occlusion with 1.5-mm fossae, except more time and care are needed. It is more a matter of understanding the concept and visualizing the objective than the need for superskilled expertise.

Modified centric occlusion is completed on the articulator as previously described. Centric occlusion is marked with one color (blue, for example). A different-colored articulating paper is placed, and the instrument is moved into right and left lateral excursions. The centric occlusion points are meticulously maintained while the lateral areas are adjusted until the incisal pin remains on the plane during both lateral excursions. With a little experience, modified centric occlusion with 1.5-mm fossae can be produced efficiently. The articulator settings and modified incisal guidance (see Figs 6c and 6d) create the occlusal anatomy in the same manner as typical occlusal configurations (see Figs 6a and 6b).

Since the technique described in this report strives to provide a small area of contact rather than point contact for centric occlusion, an appropriate amount (0.5 mm) of freedom of movement should be provided anterior to centric occlusal contact. In effect, the 1.5-mm horizontal fossa is extended anteriorly to prevent locking of the occlusion into the most retruded border position of centric relation. This can be accomplished in several ways, but is simplest to achieve after modified centric occlusion has been fabricated posteriorly for both lateral excursions. The incisal table is rotated to its original horizontal position (0 degrees), and 0.5 mm of protrusive freedom of movement is accomplished on the articulator by occlusal adjustment. With the aid of the two-color marking system, centric contact can be maintained.

For those clinicians who favor a canine-protected occlusion, the author suggests the provision of some degree of freedom of movement on the horizontal fossae in centric occlusion prior to eccentric excursions. The author does not underestimate the clinical difficulties encountered in applying this concept to occlusion with steep vertical overlap of the natural teeth; however, with implant-supported prostheses, the increased available space removes this obstacle.

To provide a harmonious protrusive excursion anterior to the established 0.5 mm, protrusive guidance on the incisal table should be reset as previously described (see Figs 10a to 10c). The restorations should be adjusted for harmonious protrusive excursions with the two-color marking system to preserve centric occlusal contact.

Intraoral Occlusal Adjustment

To efficiently correct centric occlusion deflective contacts, 0.0005-inch mylar strips held in a hemostat are placed between each contacting cusp. The patient must be instructed to maintain contact and not release occlusal pressure on the mylar strip as it is pulled laterally. This procedure can easily identify the offending cusp. Once identified, thin articulator paper is used to mark the completely dry occlusal surfaces. Pressure-indicating marking tape (Micro-O-Reg, Pulpdent) used on completely dry occlusal surfaces will further differentiate those areas requiring refinement. Although the patient may tap the teeth together firmly, the pressure-marking tape will indicate only the deflective areas. Conversely, when the correction process is completed, the contacting areas will have discrete markings, indicating an evenly distributed occlusal contact.

In the author's clinical opinion, the centric occlusion adjustment technique should vary depending on the type of prosthesis support. When complete tooth-supported or complete implant-supported prostheses are adjusted, the technique should be similar because the supporting structures have comparable stiffness and/or flexion.[5,26]

Problems arise when a free-standing implant-supported prosthesis functions in the same arch as natural teeth. These difficulties result from the differences in the relative flexion provided by the resilience of the periodontal ligament compared to the stiffness of implants and bone. Therefore, with light occlusal contact the natural teeth and implant-supported prosthesis may have relatively even loading. However, as more occlusal pressure is applied, the periodontal ligament resilience shifts the load to the implants, which provide extremely stiff support. Special occlusal adjustment techniques are required that are not possible to account for on the articulator, where everything is equally rigid.

A principle can be stated that whenever two structures of dissimilar flexion and stiffness are tied together or interact occlusally, the structure with the greatest stiffness bears much more of the load.[5,26] Currently there is no "scientific" way to adjust the occlusion for dissimilar flexion and stiffness of intraoral supporting structures. The technique suggested here is anecdotal and based on empirical clinical experience in the attempt to solve a difficult clinical problem to prevent implant overload.

First, the occlusion is adjusted until there is even resistance to pulling on the 0.0005-inch mylar tape between the free-standing implant-supported prosthesis and the natural teeth. Then the adjustment process is continued only on the implant-supported prosthesis until the tape can just be pulled through with a slight drag without catching. Pressure-marking tape (with the patient tapping forcefully on dry occlusal surfaces) should leave no markings on the implant-supported prosthesis. This process may be required annually, since natural teeth change their position in bone, while observations so far indicate that osseointegrated implants do not migrate.

Intraoral eccentric occlusal adjustment follows the well-established two-color marking procedures,[7,8,23] with the exception that special care is required to maintain harmonious centric occlusal contact over the area of the 1.5-mm fossae.

Summary

The hypothesis was presented that loading forces on an implant and supporting bone are influenced by the anatomy of the occluding surfaces (impact area). The resultant lines of force are usually inclined laterally rather than vertically because a true cusp-to-horizontal fossa seldom exists. Physiologic variability of centric relation also suggests a small area of centric occlusion, rather than a precise contact, would help reduce implant loading. Several methods have been suggested to reduce lateral forces on implants and supporting bone by altering the occlusal position and/or decreasing cusp inclines; however, to accomplish more favorable vertical lines of force, a modified occlusal anatomy containing 1.5-mm horizontal fossae instead of occlusal grooves has been recommended for posterior prostheses. The opposing cusps should be narrowed, which will produce a true cusp-to-horizontal fossa relationship in a practical range of motion from the point of centric contact. Modification of typical semiadjustable articulator procedures were recommended to produce these results in a simple, practical, and cost-effective manner. Intraoral occlusal adjustment techniques have been described for the modified occlusal restorations containing 1.5-mm horizontal fossae.

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