Therapeutic Biomechanics Concepts and Clinical Procedures to Reduce Implant Loading. Part I.

Lawrence A. Weinberg, DDS, MS, FACD, FICD

A new approach called therapeutic biomechanics that uses 5 possible corrective procedures that can be used in conjunction with each other to reduce implant loading has been suggested. These procedures are the following: (1) a cross-occlusion (to reduce horizontal implant offset); (2) the head (hex) of the implant should be placed as close to the midline of the restoration as possible; (3) angled or custom reangulated abutment; (4) shallow cusp inclines; and (5) modified centric occlusal anatomy. On maxillary anterior restorations, a horizontal lingual stop redirects the resultant line of force in a vertical direction much closer to the implant and supporting bone. Part II of this paper will focus on laboratory and clinical procedures to implement the concept of therapeutic biomechanics.

KEY WORDS

Reactive biomechanics
Therapeutic biomechanics
Horizontal implant offset
Angulated abutment
Modified centric occlusal anatomy

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Introduction

The clinical process of diagnosis and treatment planning for osseointegrated prosthesis is influenced by long-standing successful design concepts for tooth-supported prosthesis.[1] However, the biomechanical concepts of force distribution associated with periodontal ligament flexion[2] cannot be equated with the stiff osseointegrated/implant interface.[3] The biomechanics is further complicated when a mixed prosthesis utilizing natural teeth and implants supporting the same prosthesis is required.[4]

It is generally accepted that implant overload is the primary cause of failure after loading,[5] and vertical force is tolerated by supporting bone more effectively than lateral force.[6] However, in the author's opinion, corrective and remedial biomechanical designs have been neglected. This article will focus on the clinical variants that produce implant loading[7] and a diagnostic process called therapeutic biomechanics that alters each biomechanical factor in a remedial manner in order to diminish the accumulative effect that causes implant overload.[8]

Reactive Biomechanics

All physiological reactions do not take place in an isolated manner. Each factor has an accumulative effect on the collective whole. These factors are (1) muscle force, (2) cusp inclination, (3) residual bone location and quality, (4) position of the implant, (5) location of the prosthesis, (6) physiological variation, and (7) abutment design. A simple cartoon helps to visualize that these factors are interrelated and accumulative, and if no corrective plan is utilized to reduce implant loading, the process is called reactive biomechanics (Figure 1).[8]

THERAPEUTIC BIOMECHANICS

Therapeutic biomechanics is the procedure of changing in a remedial manner each biomechanical factor illustrated in Figure 1 in the physiological chain of events in order to diminish the accumulative result, which causes implant overload (Figure 2).

Clinical variants

Four clinical variants (cusp inclination, implant inclination, horizontal implant offset, and vertical implant offset) were compared mathematically in relation to torque (moment) production.[7] Three measuring points at the gold screw, abutment screw, and at the third screw thread of the implant were used. Since the values in these 3 areas are consistent relative to each other, for the sake of simplicity the average is used for each clinical situation (Figure 3).

Cusp inclination

For every 10° increase in cusp inclination, there is an average 30% increase in torque production. This was the most variation in torque production found in the 4 clinical variants (Figure 3).

Implant inclination

An increase in 10° in implant inclination produced only an average increase in torque of 5% (Figure 3).

Horizontal implant offset

For every 1 mm of horizontal implant offset, there is an average 15% change in torque production (Figure 3). This is second only to the effect of cusp inclination on torque production.

Vertical implant offset

For every 1 mm of vertical implant offset there is only an average 5% change in torque production (Figure 3).

Summary

The wide variation in torque production, from the 4 clinical variants, is an essential tool in therapeutic biomechanics procedures. As will be discussed shortly, the clinician not only can reduce each torque-producing variant individually, but an additional option is available to substitute a low torque-producing variant for a high-producing variant in order to bring about less accumulative implant loading.

THERAPEUTIC BIOMECHANICS

Cusp inclination

The first step to lessen implant loading is the reduction of cusp inclination. For instance, occlusal loading on a working cusp incline produces a resultant line of force (*F*), which is perpendicular to the steep cusp inclination (Figure 4). Torque is produced by the force (*F*) times the perpendicular distance from the maximum implant loading area located approximately at the level of the third screw thread (Figure 4).[9] A therapeutic biomechanics reduction of 10° in cusp inclination produces an average 30% reduction in torque (Figure 4). A visual way to evaluate torque is to compare the length of the distance arm from the implant to the resultant line of force (Figure 4).

Altered restoration position (cross-occlusion)

A normal buccolingual occlusal relationship is shown on the left (Figure 5). The restoration is repositioned in cross-occlusion to decrease the horizontal implant offset relative to the residual bone (Figure 5). When this side functions in working-side relationship, the normal buccolingual occlusion produces exaggerated torque. By comparison, the cross-occlusion produces less torque as measured by the shortened work arm (Figure 6).

Aesthetics and contraindications of cross-occlusion

Cross-occlusion may be contraindicated when an adjacent posterior natural tooth is in the normal buccolingual relationship. However, when cross-occlu-

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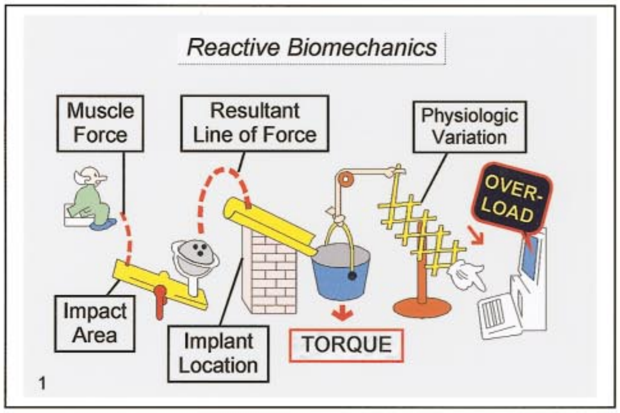
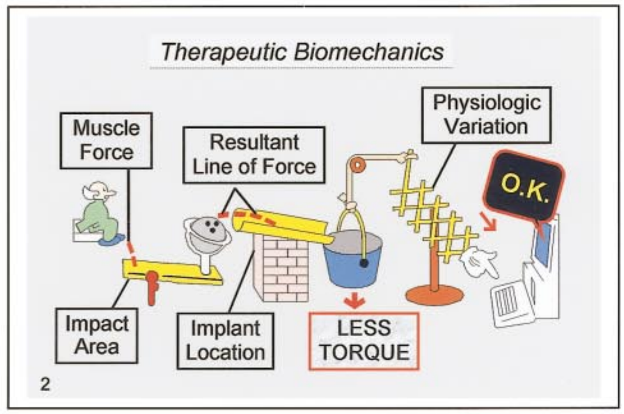
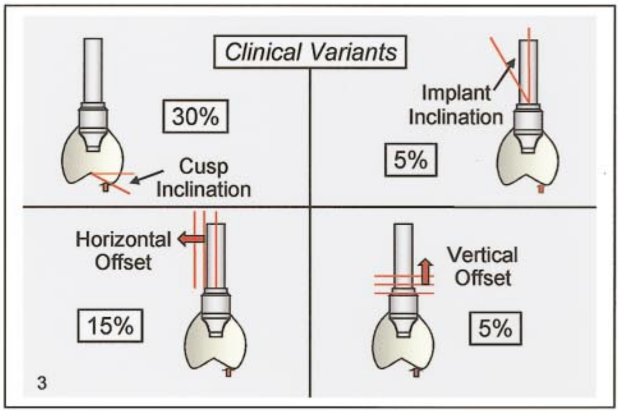
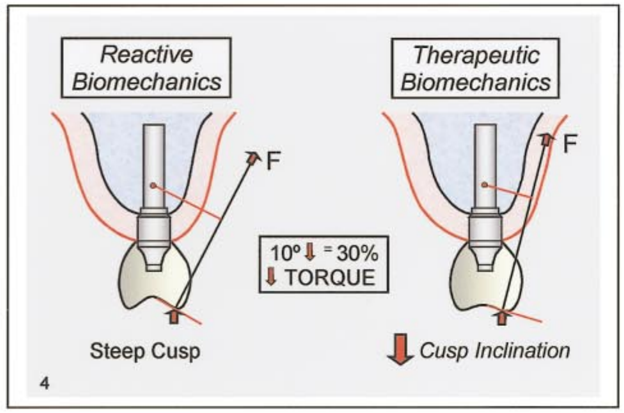
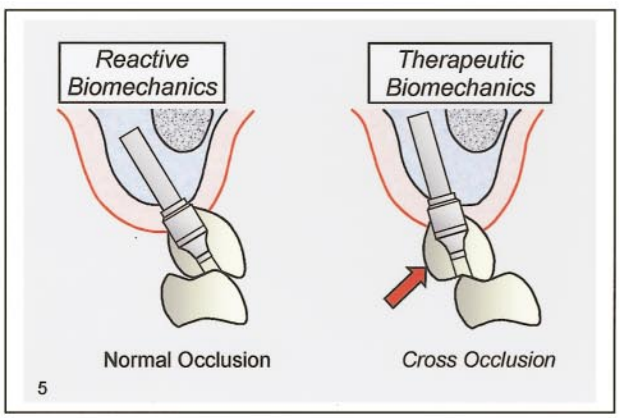
FIGURES 1–8. FIGURE 1. A cartoon illustrates the interrelation and accumulative nature of all physiologic biomechanics factors that produce implant loading. When no corrective plan is used, the process is called reactive biomechanics. FIGURE 2. Therapeutic biomechanics is the procedure for remedial biomechanics changes in the physiologic chain of events in order to diminish the accumulative result that causes implant overload. FIGURE 3. For every 10° increase in cusp inclination, torque increases an average of 30% (upper left-hand side). An increase of 10° in implant inclination produces an average increase in torque of 5% (upper right-hand side). For every 1 mm of horizontal implant offset, there is an average change in torque of 15% (lower left-hand side). A 1-mm increase in vertical implant offset only increases the torque by an average of 5%. FIGURE 4. Vertical occlusal force on the working cusp incline produces a resultant line of force (*F*) perpendicular to the inclination (left-hand side). A therapeutic reduction of 10° in cusp inclination results in an average reduction in torque of 30% (right-hand side). FIGURE 5. A normal buccolingual occlusal relationship is shown on the left-hand side. In order to reduce the horizontal implant offset, the restoration is placed in cross-occlusion (right-hand side). FIGURE 6. When functioning in the working-side relationship, the normal occlusion produces exaggerated torque as seen by the long work arm (left-hand side). With the same cusp inclination, the cross-occlusion produces less torque in the working relationship, as observed by the reduced working arm distance (right-hand side). FIGURE 7. The usual straight-line configuration of the implant/abutment/access channel is shown on the left-hand side. The implant head is placed near the center line of the restoration (right-hand side). This reduces the horizontal implant offset by 2 mm, which diminishes the torque an average of 30%. Implant inclination of 10° may be required, which increases the torque an average of only 5%. The net savings in torque is 25% (right-hand side). FIGURE 8. Due to the location of the sinus, the normal posterior occlusion produces a horizontal implant offset (left-hand side). Cross-occlusion reduces the horizontal implant offset, decreasing torque.

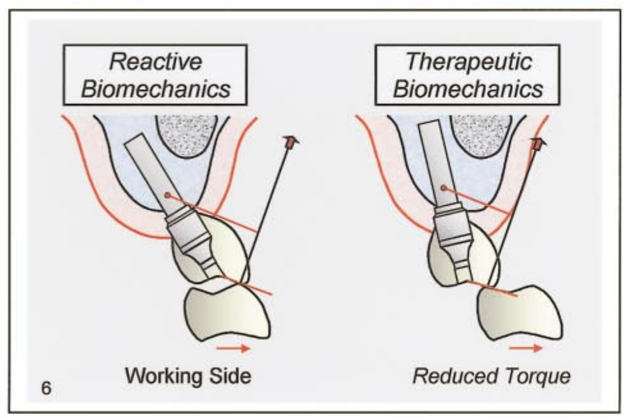

Reactive Biomechanics
Muscle Force
Resultant Line of Force
Physiologic Variation
OVER-LOAD
Impact Area
Implant Location
TORQUE
1

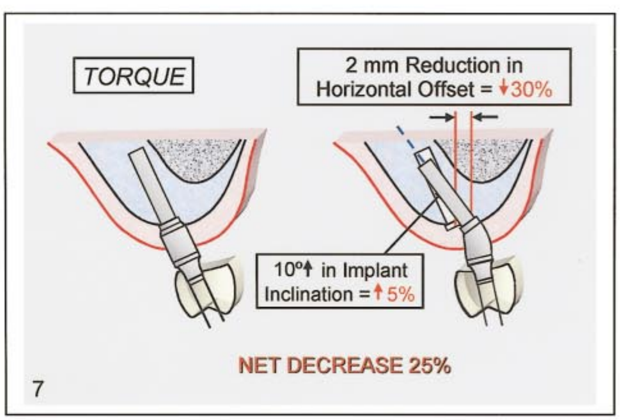

Therapeutic Biomechanics
Muscle Force
Resultant Line of Force
Physiologic Variation
O.K.
Impact Area
Implant Location
LESS TORQUE
2

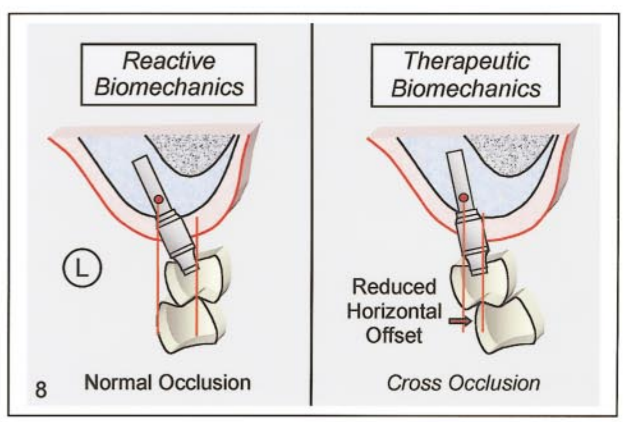

Clinical Variants
30%
Cusp Inclination
Implant Inclination
5%
Horizontal Offset
15%
Vertical Offset
5%
3


Reactive Biomechanics
Therapeutic Biomechanics
F
F
10º ⇩ = 30%
⇩ TORQUE
Steep Cusp
Cusp Inclination
4


Reactive Biomechanics
Therapeutic Biomechanics
Normal Occlusion
Cross Occlusion
5


Reactive Biomechanics
Therapeutic Biomechanics
Working Side
Reduced Torque
6


TORQUE
2 mm Reduction in Horizontal Offset = ↓30%
10º↑ in Implant Inclination = ↑5%
NET DECREASE 25%
7


Reactive Biomechanics
Therapeutic Biomechanics
L
Reduced Horizontal Offset
Normal Occlusion
Cross Occlusion
8

sion is utilized, aesthetics are usually not a problem because the first bicuspid is in normal B-L relationship, the second bicuspid in cusp to cusp occlusion, and only the first molar is in cross-occlusion. Tongue space can be provided by narrowing the buccolingual width of the molars. Whenever the occlusal position is modified (cross-occlusion), the planned occlusion should be provided in the provisional restorations in order help patient adaptation and problem solving prior to the construction of final restorations.

Altered implant position

Another fundamental therapeutic biomechanics process utilizes the disparity in torque production from the 4 clinical variants discussed in Figure 3. The process consists of substituting a low torque-producing factor for a high torque-producing factor. For instance, a standard implant/abutment/restoration design facilitating the access channel exiting the center of the restoration is shown in Figure 7. The implant head should be placed as close to the center line of the restoration as possible, thus reducing the horizontal offset. In this case a 2-mm reduction of horizontal implant offset reduces the torque by approximately 30% (Figure 7). Due to the sinus, the implant must be inclined 10°, which only increases the torque by 5%. This implant inclination requires an angulated or custom reangulated abutment in order to provide parallelism or favorable access channel location (Figure 7).

Favorable sinus location

Reduction of horizontal implant offset may not always require abutment reangulation. When the location of the sinus permits, the normal occlusal relationship does not necessarily require abutment angulation when a cross-occlusion is utilized (Figure 8). The criteria is to first place the head of the implant as close to the midline of the repositioned restoration as possible, followed by the appropriate implant inclination required by the residual bone topography. The abutment design is selected last in order to provide the required parallelism and/or access.

Physiologic variation

The standard occlusal anatomy of cusp inclines meeting in a central grove is shown on the left-hand side of Figure 9. Theoretically, the mandibular cusp causes buccal and lingual lines of force, which produce a vertical resultant line of force (Figure 9). However, clinical experiments on the replication of centric relation records have all indicated that there is a physiologic variation of approximately ±0.4 mm in relation to time,[10] different recording methods,[11] muscular deconditioning,[12] and muscle tone.[13] As a result of this ever-present physiologic variation, the lateral shift in centric occlusion will result in buccal or lingual inclined resultant lines of force distributed to the supporting bone (Figure 9).

Modified occlusal anatomy

A posterior horizontal fossa of 1.5 mm has been suggested to compensate for physiologic variation.[14] The concept of a horizontal fossa is not new and has been called ''long centric'' by Mann and Pankey.[15] However, the technique as originally described used intraoral, functionally generated records, which have not become popular. A simple laboratory technique has been described[14] that is designed to produce a modified occlusal anatomy containing a 1.5-mm horizontal fossa (Figure 10). With this configuration, a mandibular cusp will produce a vertical resultant line of force within the expected range of physiologic variation (Figure 10).

POSTERIOR MANDIBULAR BONE LOSS

Pattern of bone loss

The pattern of posterior bone loss has an impact on biomechanics. The lingual axial inclination of the most posterior molars is in the range of 33° to 35°. The inclination decreases as the location moves anteriorly, which becomes almost vertical at the bicuspids (Figure 11). At the canine, the axial inclination is buccal in direction, which increases in severity toward the midline. The incisors are markedly inclined labially (Figure 12). When the teeth are lost, the bone atrophies along the root inclination toward the basal bone.

Biomechanical effect

The biomechanical effect of the pattern of bone loss is to move the implant-supporting bone lingual to the occlusal impact area. The resultant torque that is produced depends on the character

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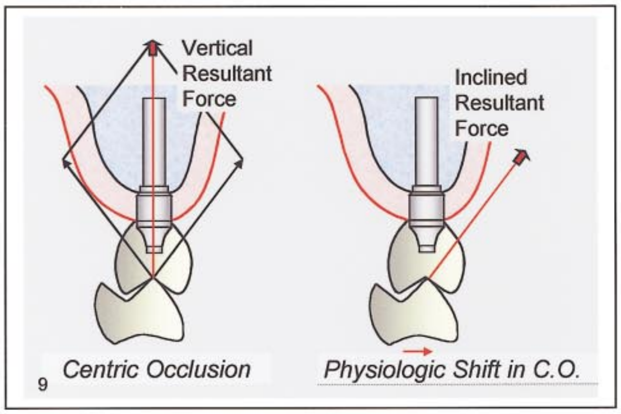
FIGURES 9–16. FIGURE 9. A standard occlusal relationship of a cusp articulating with a line angle theoretically produces buccal and lingual lines of force that produce a vertical resultant line of force (left-hand side). Physiologic variation in the range of ±0.4 mm produces a buccal (or lingual) inclined resultant line of force (right-hand side). FIGURE 10. A modified occlusal anatomy containing a 1.5-mm horizontal fossa is suggested (right-hand side). With this anatomy, physiologic variation produces a vertical, rather than an inclined, resultant line of force (left-hand side). FIGURE 11. The posterior molars have an exaggerated lingual axial inclination (left-hand side). This inclination decreases as the location moves anteriorly. The bicuspids are more vertical (right-hand side). FIGURE 12. The canine is inclined buccally (right-hand side), whereas the incisors are more severely inclined labially (right-hand side). Bone loss follows the axial inclination of the teeth. FIGURE 13. Usually the occlusion is extremely lingual to the residual bone in the second molar area. Excessive torque can result from the resultant line of force falling at a great distance from the implant and supporting bone. FIGURE 14. Therapeutic biomechanics procedures applied: (a) reduced cusp inclination; (b) head of implant placed close to center line of restoration; (c) angled abutment. All reduce the distance arm of the resultant line of force from the implant, effectively reducing torque. FIGURE 15. With the usual configuration, working-side contact can produce a resultant line of force that falls at an exaggerated distance arm (D) from the implant and supporting bone. FIGURE 16. Three possible therapeutic biomechanics procedures are illustrated: (a) implant head placed over the midline of the restoration; (b) angled abutment; (c) shallow cusp inclines. In combination, these therapeutic procedures dramatically reduce the torque as demonstrated by the shortened work arm.



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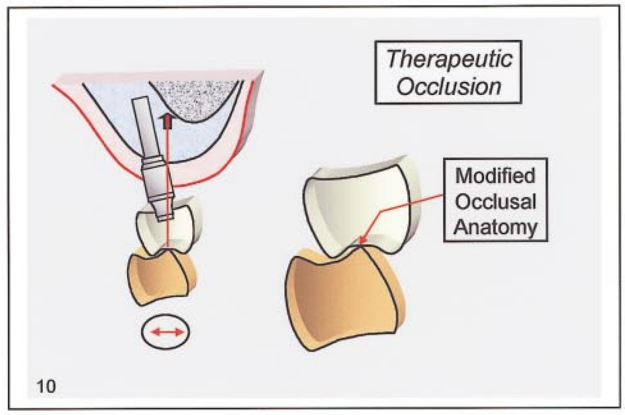

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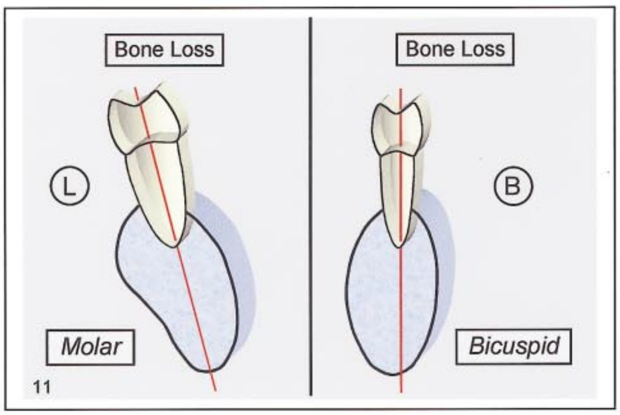

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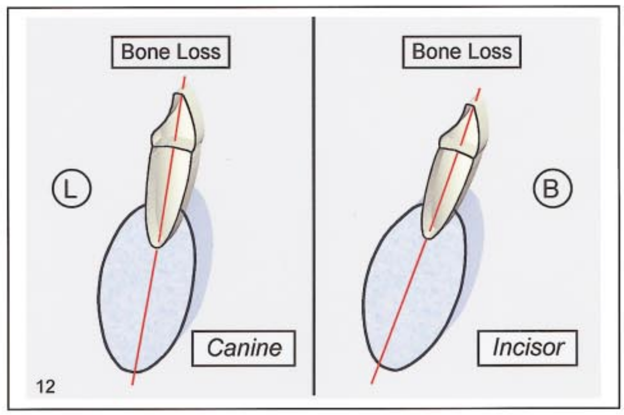

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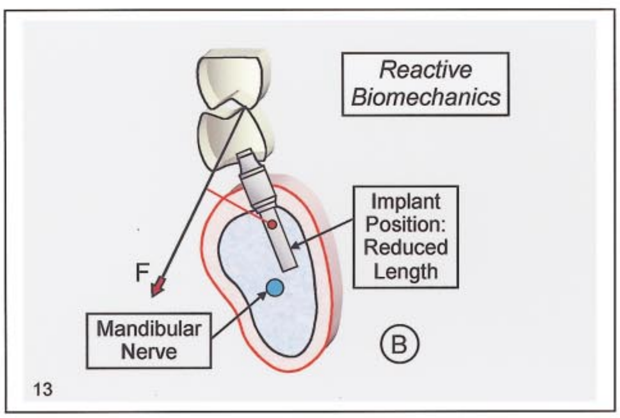

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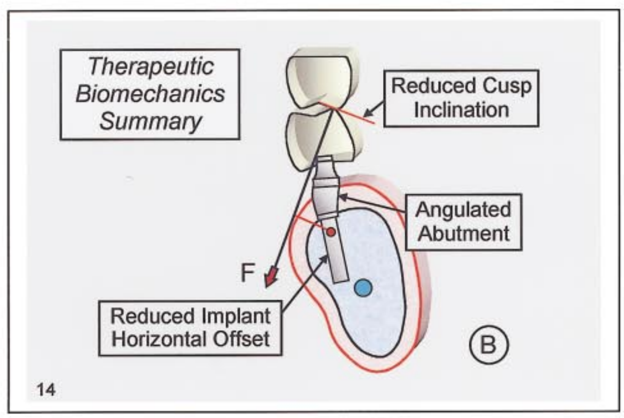

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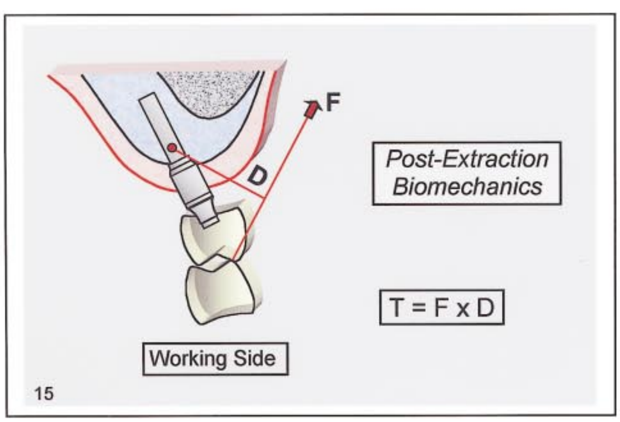

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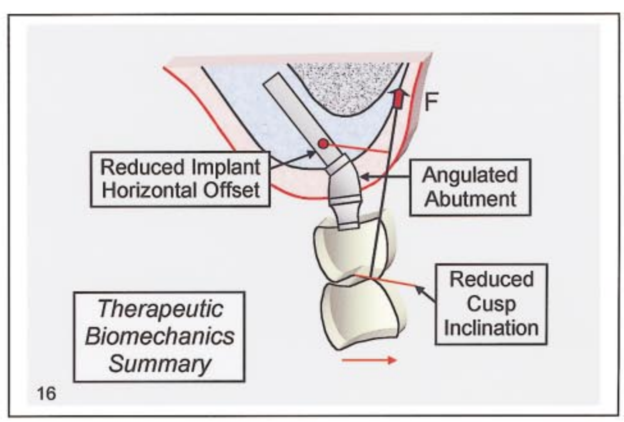

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of the impact area and the direction of the resultant line of force relative to the implant and its supporting bone.[2–4,7] In this paper, the reactive biomechanics to these events will be described, followed by the therapeutic biomechanics remedial steps recommended to reduce torque and implant overloading.

POSTERIOR MANDIBULAR BIOMECHANICS

All too often the reactive biomechanics posteriorly is exaggerated by the required lingual position of the restoration relative to the residual bone (Figure 13). Often a bad situation is made worse by the combined effect of the loss of vertical bone height and the location of the mandibular nerve. This usually results in the buccal placement of the implant and excessive torque due to the long working arm (reactive biomechanics) generated by the exaggerated lingual resultant line of force created by the occlusion (*F*, Figure 13).

THERAPEUTIC BIOMECHANICS

The exaggerated implant torque previously described (Figure 13) is contrasted with the reduced torque (shorter working arm) produced in Figure 14 as a result of a series of therapeutic biomechanics remedial procedures: (1) the cusp inclination is reduced, causing the resultant line of force to pass much closer to the implant and supporting bone; (2) the head of the implant is placed closer to the midline of the restoration, which reduces the horizontal implant offset; and (3) the angulated abutment facilitates the required parallelism and/or access. It should be emphasized that the precise location and inclination of the implant, safely avoiding the mandibular canal, is a practical clinical result of a precise three-dimensional guidance system for implant insertion.[16,17]

POSTERIOR MAXILLARY BONE LOSS

Pattern of bone loss

Often the posterior maxillary residual alveolar bone is more restricted not only as a result of the lingual pattern of bone loss, but the location of the sinus and frequent fracture of the buccal plate of bone during surgery. As a result, the postextraction biomechanics is extremely unfavorable. With the usual occlusion and implant/abutment/restorative configuration, working-side occlusion produces a resultant line of force that falls at an exaggerated distance from the implant and supporting bone (distance arm [D], Figure 15). This usually produces an extremely high level of torque resulting in implant overload.

Therapeutic biomechanics

Assuming the prosthesis cannot be placed in cross-occlusion, there are several remedial therapeutic biomechanics procedures that should be used (Figure 16): (1) marked reduction in cusp inclination causes the resultant line of force to pass much closer to the supporting bone; (2) the head of the implant is positioned in line with the midline of the restoration, reducing the horizontal implant offset; and (3) an angled, or reangulated abutment, provides parallelism and/or access. The therapeutic biomechanics process reduces the distance of the work arm (Figure 16) and can reverse a completely untenable (reactive biomechanics) implant-overloaded system (Figure 15).

Cross-occlusion

For comparison purposes, the original reactive biomechanics working-side occlusion is shown on the left-hand side of Figure 17, with the exaggerated torque-producing, long working arm. In addition to all the therapeutic biomechanics remedial changes previously utilized in Figure 16, a cross-occlusion further reduces the working arm and resulting torque (Figure 17, right-hand side).

Summary of posterior maxillary therapeutic biomechanics

There are 5 possible therapeutic biomechanics procedures that can be used in conjunction with each other in the maxillary posterior area (Figure 18): (1) cross-occlusion (reducing horizontal implant offset); (2) placement of the implant head as close to the midline of the restoration as possible; (3) angled abutment; (4) shallow cusp inclines; and (5) modified centric occlusal anatomy (1.5 mm horizontal fossae, Figures 10 and 18). It may not be practical to utilize all 5 procedures in some clinical cases. This procedure does not necessarily rule out sinus lifts, but it is a valuable alternative.

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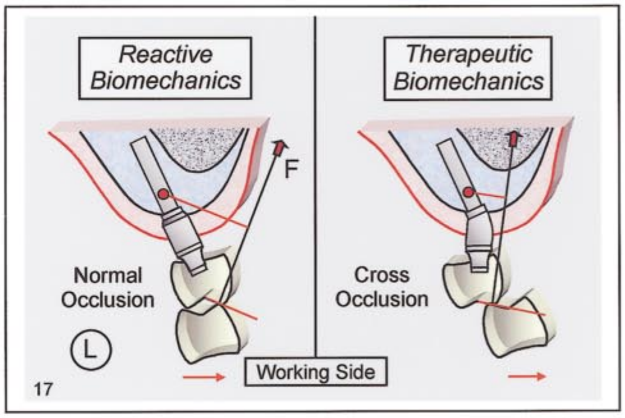
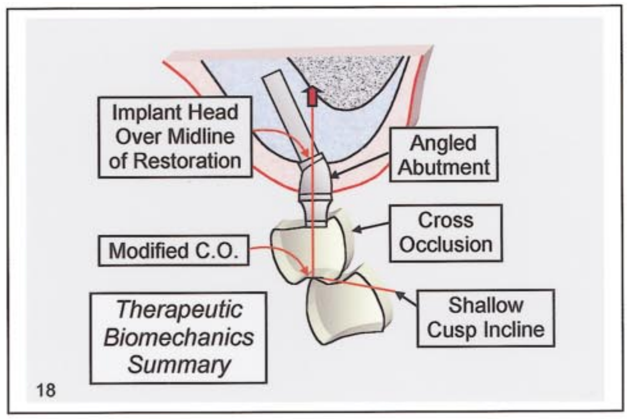
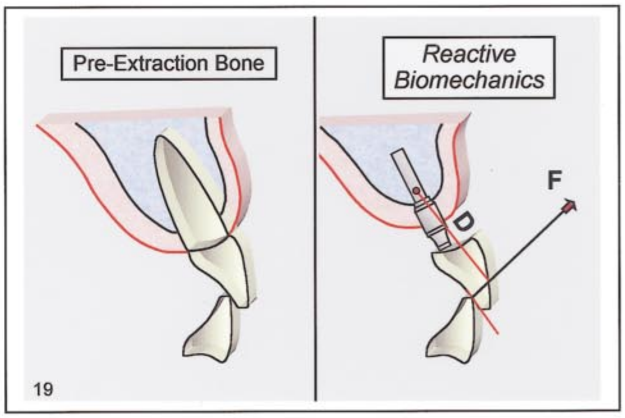
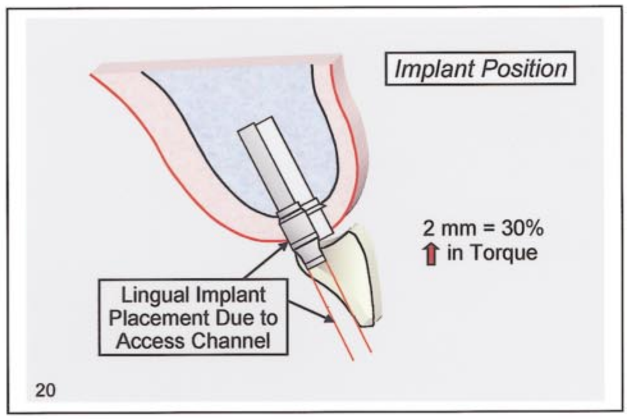
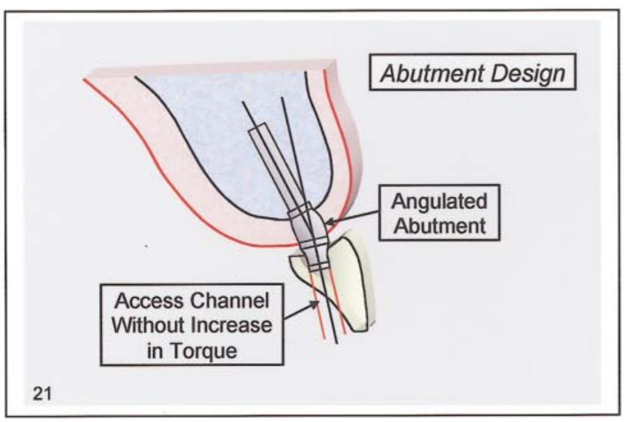
FIGURES 17–24. FIGURE 17. For comparison purposes the reactive biomechanics are illustrated in working occlusion on the left-hand side, demonstrating exaggerated torque. Therapeutic biomechanics on the right-hand side utilizes a cross-occlusion in addition to decreased cusp inclination previously shown in Figure 16. The combination provides maximum torque reduction (right-hand side). FIGURE 18. The five possible therapeutic biomechanics procedures are shown: (a) cross occlusion; (b) implant head in midline of restoration; (c) angled abutment; (d) shallow cusp inclines; and (e) modified centric occlusal anatomy. All combine to dramatically reduce torque. FIGURE 19. Pre-extraction bone is illustrated (left-hand side). Postextraction reactive biomechanics with a deep vertical overlap produces an exaggerated inclined resultant line of force and a very long distance arm (D), which produces implant and retaining-screw overload (right-hand side). FIGURE 20. Lingual implant placement for the access channel increases torque (2 mm increases the torque 30%). FIGURE 21. Placing the head of the implant in line with the center of the restoration, and an angled abutment, provides an access channel without torque increase. FIGURE 22. Steep vertical overlap incline contact produces a steep resultant line of force (*F*) that can result in implant and retaining screw overload due to the long work arm (D). FIGURE 23. A horizontal lingual stop, plus the previously described therapeutic biomechanics changes, results in a dramatic reduction in torque as evidenced by the reduced work arm (D). FIGURE 24. Horizontal lingual stops can be placed on tooth-supported fixed prosthesis (arrows).


Reactive Biomechanics
Therapeutic Biomechanics
F
Normal Occlusion
Cross Occlusion
L
Working Side
17


Implant Head Over Midline of Restoration
Angled Abutment
Modified C.O.
Cross Occlusion
Therapeutic Biomechanics Summary
Shallow Cusp Incline
18


Pre-Extraction Bone
Reactive Biomechanics
F
D
19


Implant Position
2 mm = 30%
in Torque
Lingual Implant Placement Due to Access Channel
20


Abutment Design
Angulated Abutment
Access Channel Without Increase in Torque
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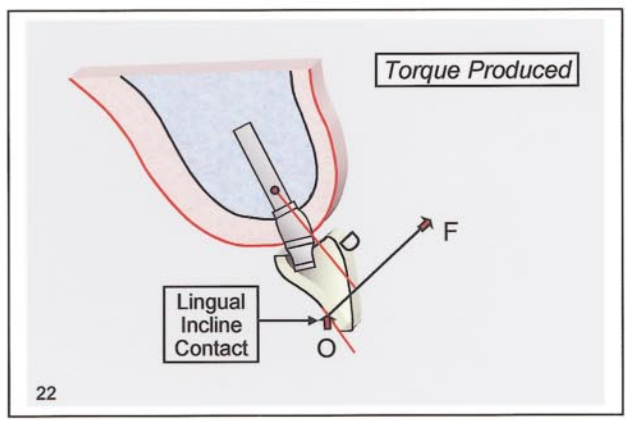
Torque Produced
D
F
Lingual Incline Contact
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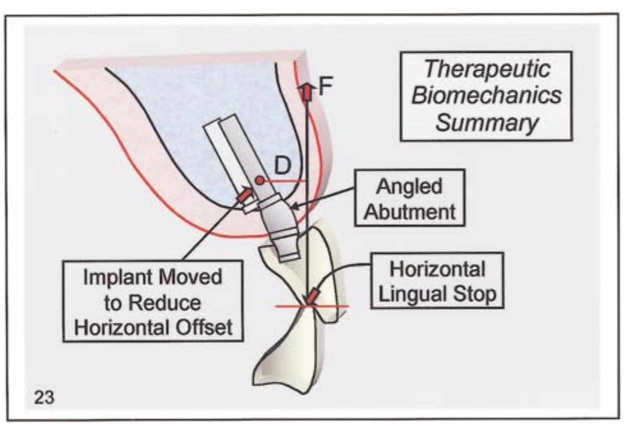
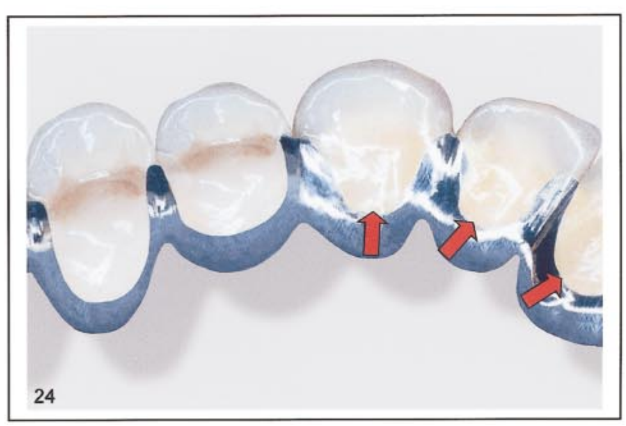

F
Therapeutic Biomechanics Summary
D
Angled Abutment
Implant Moved to Reduce Horizontal Offset
Horizontal Lingual Stop
23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ANTERIOR MAXILLARY BONE LOSS

Reactive biomechanics

Preextraction bone level is illustrated in Figure 19. Postextraction bone loss is superior and lingual (Figure 19). Aesthetic demands require the restoration to remain in the original position, which is considerably labial to the residual supporting bone (Figure 19). To compound the problem, a steep vertical overlap produces a resultant line of force (*F*), which has exaggerated labial inclination (Figure 19). The distance arm (D) is extremely long, which produces an unacceptable overload on the retaining screws, implant, and supporting bone (Figure 19).

Therapeutic biomechanics

The usual in-line configuration of the implant/abutment/restoration that is used to facilitate access channel placement increases the lingual horizontal implant offset 2 mm, resulting in a 30% increase in torque (Figure 20). It is recommended to position the implant anteriorly 2 mm in order to place the head closer to the midline of the restoration. An angled, or custom reangulated abutment, provides the access channel without an increase in torque (Figure 21).

Regardless of the labial implant placement, lingual incline contact with a deep vertical overlap produces a severely inclined resultant line of force (*F*), which induces excessive torque due to the extremely long working arm (D, Figure 22). This can be reduced by providing a horizontal lingual stop on the maxillary restoration, which will redirect the resultant line of force as vertically as possible, reducing the working arm, which effectively diminishes the torque (Figure 23). Horizontal lingual stops can also be used with tooth-supported fixed prosthesis (Figure 24).

Summary of anterior maxillary therapeutic biomechanics

Due to aesthetic demands, there are 3 possible therapeutic biomechanics procedures that can be used in conjunction with each other in the anterior maxillary area: (1) placement of the implant head as close to the midline of the restoration as possible, (2) angled abutment, and (3) maxillary horizontal lingual stop (Figure 23). It may not be practical to utilize all 3 in some clinical cases. However, to gain maximum effect from therapeutic biomechanics, optimum implant placement is recommended.

SUMMARY

All physiological processes are multileveled and interactive biomechanically. The effect is accumulative and can result in implant overload. A new approach called therapeutic biomechanics has been suggested,[8] which uses multiple corrective procedures to reduce implant loading. Previous mathematical data on clinical variables[7] suggested 5 possible corrective procedures designed to reduce torque and implant loading: (1) the head of the implant should be placed as close to the midline of the restoration as possible, and implant inclination may be required, which produces much less torque than horizontal implant offset[7]; (2) wherever possible, cross-occlusion is advocated posteriorly in order to reduce the horizontal implant offset[8]; (3) angulated or custom reangulated abutments provide parallelism and/or access; (4) posterior cusp inclination produces maximum torque[7] and should be considerably reduced; and (5) due to physiologic variability, a modified centric occlusal anatomy containing 1.5-mm horizontal fossae is recommended to maintain vertical resultant forces[14] within the range of physiological variation ($\pm$0.4 mm).[10–13]

Vertical overlap in the anterior maxilla produces a sharply inclined resultant line of force perpendicular to the impact surface. A lingual horizontal stop on the maxillary restoration (an anterior, modified, centric occlusion) redirects the resultant line of force in a vertical direction much closer to the implant and supporting bone.[8] It is not always possible to utilize all of the therapeutic biomechanics corrective procedures clinically because of limitations of space, aesthetics, and occlusal demands. However, maximum effectiveness is obtained in conjunction with a three-dimensional guidance system for implant insertion.[16,17]

REFERENCES

1. Lundeen D, Laurell L. Occlusal forces in prosthetically restored dentitions: a methodological study. *J Oral Rehabil.* 1984;11:29–37.
2. Weinberg LA. Axial inclination and cuspal articulation in relation to force distribution. *J Prosthet Dent.* 1957;7:804–813.
3. Weinberg LA. Biomechanics of force distribution in implant-supported prosthesis. *Int J Oral Maxillofac Implants.* 1993;8:19–31.
4. Weinberg LA, Kruger B. Biomechanical considerations when combining tooth-supported and implant-supported prosthesis. *Oral Surg Oral Med Oral Pathol.* 1994;78:22–27.
5. Smith DC. Dental implants: materials and design considerations. *Int J Prosthodont.* 1993;6:106–117.
6. Misch CE. *Contemporary Implant Dentistry.* St. Louis: Mosby; 1993:281–282.
7. Weinberg LA, Kruger B. A comparison of implant/prosthesis loading with four clinical variables. *Int J Prosthodont.* 1995;8:421–433.
8. Weinberg LA. Reduction of implant loading with therapeutic biomechanics. *J Implant Dent.* 1998;7:277–285.
9. Clelland NL, Ismail YH, Zaki HS, Pipko D. Three-dimensional finite element stress analysis in and around the Screw-Vent implant. *Int J Oral Maxillofac Implants.* 1991;6:391–398.
10. Grasso J, Sharry J. The duplicability of arrow-point tracing in dentulous subjects. *J Prosthet Dent.* 1968;20:106–115.
11. Kantor M, Silverman S, Garfinkel L. Centric relation recording techniques: a comparative investigation. *J Prosthet Dent.* 1972;28:593–600.

12. Calagna L, Silverman S, Garfinkel L. Influence of neuromuscular conditioning on centric relation registrations. *J Prosthet Dent.* 1973;30:598–604.

13. Celenza FV. The centric position: replacement and character. *J Prosthet Dent.* 1973;30:591–598.

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

15. Mann A, Pankey K. Oral rehabilitation. II. Reconstruction of the upper teeth using functionally generated path technique. *J Prosthet Dent.* 1960;10:151–162.

16. Weinberg LA, Kruger B. Three-dimensional guidance system for implant insertion. Part I. *J Implant Dent.* 1998;7:81–91.

17. Weinberg LA, Kruger B. Three-dimensional guidance system for implant insertion. Part II. Dual axes table. Problem solving. *J Implant Dent.* 1999;8:225–264. ■