THE EFFECT OF IMPLANT DIAMETER, RESTORATION DESIGN, AND OCCLUSAL TABLE VARIATIONS ON SCREW LOOSENING OF POSTERIOR SINGLE-TOOTH IMPLANT RESTORATIONS

Lara G. Bakaeen, DDS, MS
Sheldon Winkler, DDS
Peter A. Neff, DDS, ScD

The purpose of this study was to (1) determine in vitro the effect of narrowing the buccolingual width of the occlusal table on the untightening torque required to loosen gold prosthetic screws after subjecting implants and implant-supported restorations to occlusal loads, and (2) to compare the incidence of screw loosening and values of untightening torque of the screws among crowns supported by 1 wide-diameter as opposed to 2 standard implants after loading in vitro. The restorations were divided into 4 groups (group 1, a narrow crown supported by one 5-mm wide-diameter implant; group 2, a narrow crown supported by 2 standard 3.75-mm-diameter implants; group 3, a wide crown supported by one 5-mm wide-diameter implant; and group 4, a wide crown supported by 2 standard 3.75-mm-diameter implants). A custom-designed chewing machine was used to simulate the grinding phase of the masticatory cycle and lateral excursions. The crowns were subjected to a 6-kg load for 16,660 cycles over 5.5 hours and were loaded at the outer and inner inclines and cusp tips with an untightening loading pattern. The untightening torque was measured for the gold screws in the different groups before and after loading at 4 different locations for 8 cycles on the simulated chewing machine. A 1-way analysis of variance indicated a significant difference (P < .001) among the test groups. Pairwise multiple comparison tests (Scheffe) were carried out on mean “change scores.” Group 3 was significantly different from the other groups, which were not significantly different from each other. Restoring missing molars with 1 wide-diameter implant had a greater incidence of screw loosening as compared with 2 implants. Narrowing the occlusal table of the restoration is critical when using 1 implant to support a missing molar. The untightening torque of gold screws was not affected by changing the width of the occlusal table of crowns supported by 2 implants.
INTRODUCTION

Several clinical studies have evaluated implant-retained and supported prostheses in complete and partially edentulous patients. Although most of these investigations had a high success rate, abutment and prosthetic screw loosening was the most frequently encountered complication.1-8 Few studies have been published evaluating the outcome of single-tooth implant replacements, particularly molars.9

Clinical documentation of single-molar, implant-supported restorations is limited9 with an unknown long-term outcome.10 Several clinical studies have reported a higher complication rate for implant-supported restorations in the premolar and molar regions.11-13 The greatest amount of force is generated in the first molar region during mastication, with the chewing occurring predominantly in the first molar and second premolar regions.14,15

Becker et al16 presented the results of a retrospective analysis, which represented the first report of replacing single molars with implant-supported prostheses. Loosening of the gold retaining screws was the main complication. Balshi17 described the use of 2 implants for the replacement of a single molar and reported success at a 1-year follow up. The rationale was a better distribution of forces to the alveolar bone and greater stability of the prosthesis. In retrospective comparative analyses by Balshi et al,9,18 single molars were replaced by either 1 or 2 implant-supported prostheses. During a 3-year evaluation period, screw loosening was the most frequent complication and was predominant in the group with 1 implant. In a clinical report on wide and double implants in the posterior jaw, Bahat et al10 reported higher failure rates for single implants as compared with double implants.

The theoretical concept of “preloading” implant components was introduced to the dental profession in 1989.19 The conventional implant vertical stack is composed of the implant, abutment, abutment screw, gold cylinder, and retaining screw. When assembled, these components form 6 joints (interfaces).20

As the screws are tightened past the finger-tight stage, a preload is applied to the screw and introduces a compressive stress as the components are being clamped together.21 Forces attempting to disengage the parts are called joint-separating forces. These forces must remain below the threshold of the established clamping force and depend on many factors.20 Screw loosening occurs as a result of a change in deformation among the screw and connected members in response to an external load applied to a preloaded joint.21

Settling effect plays a critical role in screw stability. Settling occurs as the rough spots (no surface is completely smooth) flatten under load, since they will be the only contacting surfaces when the initial tightening torque is applied.22 It is assumed that 2% to 10% of the initial preload is lost as a result of settling,21 and as a result, the torque necessary to remove a screw is less than the torque used initially to place the screw.23 Thread friction is higher than the torque used initially to place the screw.20 It then decreases after repeated tightening and loosening cycles.24 It has been suggested that joints be tightened after the initial screw insertion and periodically thereafter.24

Screw loosening may be an early warning sign of biomechanical design problems or occlusal overload.25 Rangert et al19 described the implant as a system with compensating forces and a lever arm, with the axial forces and bending moments being the main types of loads acting on the implant-supported prosthesis. Axial forces are more favorable. A bending moment tends to produce rotation of a rigid body. Bending moments could be the result of axial forces remote to a straight line combining 2 or more implants or transverse forces. In single-tooth implants, unless the load is directed centered and parallel to the implant, a bending moment will always be present, even with a short lever arm.22

Several authors recommended reducing the width of the occlusal table to favor axial load on the implant in nonaesthetic regions.12,26-29 Reducing the buccolingual width of a restoration is not a new concept in dentistry. In 1935, Schuyler30 advocated reducing the contacting surfaces as a means of adjusting occlusal dysharmony, which could result in occlusal trauma. Dykenma31 advocated narrowing the buccolingual dimensions of pontics up to 40% as a means of reducing load on the abutments. Weinberg32 suggested narrowing the occlusal table and/or moving the occlusal contact area more in line with the implant location as one means to reduce the shearing stress on the retaining screws.

Since a molar is not equally wide as it is long, it is difficult to provide optimal root-form support with 1 cylindrical implant. The placement of a crown that extends beyond the diameter of the implant both mesiodistally and buccolingually are potential biomechanical problems, which can lead to screw loosening, fracture, and implant fatigue. The use of 2 implants may help reduce these forces.

The purpose of this study was to (1) determine the effect of narrowing the buccolingual width of the occlusal table on the unloading torque required to loosen the gold screws after subjecting implants and implant-supported structures to occlusal loads, and (2) to compare the incidence of screw loosening and values of unloading torque of screws between implants and implant-supported prostheses, unless the load is directed centered and parallel to the implant, a bending moment will always be present, even with a short lever arm.22

MATERIALS AND METHODS

Two abutment-implant combinations (2-implant assembly and wide-body assembly) were tested with 9.8-mm (wide) and 8.4-mm (narrow) buccolingual...
gular widths measured from cusp tip to cusp tip. Each group had a sample size of \( n = 8 \) (for convenience). Each assembly consisted of 1 of the following vertical stacks:

- Two-implant assembly: two 3.75-mm-diameter implants 10 mm in length (SDCA 062; Nobel Biocare, Yorba Linda, Calif); 2 Estheticone abutments with a 4-mm cuff height (SDCA 136); 2 abutment gold screws; 2 gold cylinders (DCA 225) with antirotational hexagonal features; and 2 gold screws (DCA 074).
- Wide-body assembly: single wide-body implant 5 mm in diameter and 10 mm in length (SDCA 146; Nobel Biocare); Estheticone abutment with a 4-mm collar height (SDCA 136); abutment gold screw; gold cylinder (DCA 225) with an internal hexagon to provide antirotation; and a gold screw (DCA 074).

The assemblies were divided into 4 groups (group 1, a narrow crown supported by one 5-mm-wide-diameter implant; group 2, a narrow crown supported by 2 standard 3.75-mm implants; group 3, a wide crown supported by one 5-mm-wide-diameter implant; and group 4, a wide crown supported by 2 standard 3.75-mm implants).

A hollow, custom-machined aluminum cylinder (outer diameter 38 mm, inner diameter 15.5 mm, height 15 mm), was lubricated and filled with clear resin (Coe Ortho-Acrylic Resin II; GC America, Chicago, Ill) using a salt and pepper technique. The resin was allowed to polymerize for 20 minutes in warm water (110°F) under pressure (20 pounds per square inch [psi]) according to the manufacturer’s instructions. Cylindrical resin blocks were made to support the abutment-implant combinations. Implants were embedded in the resin cylinders up to the level of the abutment collar. For the 2-implant assembly, the interimplant distance was 1.5 mm.

To ensure straight and parallel placement of the implants, each cylindrical resin block was placed on a dental surveyor table so that the top and bottom surfaces of the block were perpendicular to the arm of the surveyor. This was verified by the use of a bubble gauge. A hexagonal screwdriver was attached to the arm of the surveyor, and each abutment was screwed to a finger-tight stage into 1 of the implants. The gold cylinders were screwed into the abutments by tightening the prosthetic gold screws to a finger-tight stage. The prosthetic gold screws used for the initial wax-up were not used during the testing procedures. The assembly was secured in the screwdriver on the arm of the surveyor, and each implant was lowered into the appropriate resin block. The implants were fixed in place by adding acrylic. A 6-BTG-A Tohnichi torque gauge (Tohnichi America Corporation, Northbrook, Ill) was used to ensure that an accurate and reproducible force was applied to the abutment screw and later to the gold prosthetic screw. Each abutment was tightened according to the manufacturer’s instructions (20 N-cm for the abutment screw and 10 N-cm for the flat-headed gold screw).

An electroplated split mold (Universal Dental Company, Montgomeryville, Pa) for fabrication of 22° cusp angle mandibular first molars was used to obtain accurate and consistent reproduction of the wax patterns for the restorations (Figure 1). Two molds (T, Y) were used to obtain different occlusal table dimensions. Mold T was 8.4-mm in buccolingual width (narrow), and mold Y was 9.8-mm (wide) in buccolingual width.

The molds were secured on the surveyor table by dental stone, and the tilt of the table was adjusted to place the implants perpendicular to the occlusal table. A hole was drilled in the bottom of each resin block to accommodate a surveyor analyzing rod. The analyzing rod was notched along its length for retention within the resin.

Each block was placed on the surveyor table so that it was resting on the flat head of the prosthetic gold screw (Figure 2). The rods were lowered into the holes at the base of the blocks and fixed in place by adding acrylic resin. Each block holding the implant, screwed abutment, and gold cylinder was lowered into the mold until the top of the gold cylinder was 1.5 mm from the replica of the occlusal surface. This position was maintained by means of a plastic sleeve indexed and fixed to the border of the mold opposite the replica using pattern resin (GC Pattern Resin; GC America, Chicago, Ill). The sleeve housed a free-moving, pointed, plastic rod (Williams Plastic Sprue; Williams Gold Refining Company, Buffalo, NY) that served as a pointer (Figure 3).

Heated wax (Yetti; Keystone Industries, Cherry Hill, NJ) was dropped into the mold using a dropper. The single implant assembly was lowered into the mold so that the gold screw was centered over the approximate area of occlusal contact.
the central fossa. This position was then indexed to ensure reproducibility. The 2-implant assembly was placed so that the gold screws were over the approximate area of the mesial and distal triangular fossae. To reduce the possibility of distortion of the wax pattern over the 2 gold cylinders, pattern resin was used to connect the gold cylinders prior to dipping them in wax. The position was then indexed. The remaining part of the crown was waxed free hand to the gold cylinder. The screw holes were defined and the crowns unscrewed.

The wax patterns were sprued and invested (Beauty Cast; Whip Mix Corporation, Louisville, Ky) using a lined casting ring. The investment was allowed to bench set for 30 minutes according to the manufacturer’s instructions, and then burned out at 900°F at a rate of 18° per minute. Type III gold alloy (Majority; Ney Dental International, Bloomfield, Conn) was used to cast the full crown restorations. The crowns were devested and cleaned ultrasonically for 20 minutes. The crowns were then placed in a pickling solution for 10 minutes and finished and polished by conventional methods.

The torque gauge was used to ensure that each abutment screw was torqued to 20 N-cm. The gold crowns were then fixed to the corresponding implants with flat-headed gold screws and tightened to 10 N-cm. The access holes were filled with cotton pellets and sealed with composite resin.

A custom-designed chewing machine was constructed (Figures 4 and 5A and B) to evaluate the untightening torque of the gold screws after function.

A gold crown representing the opposing tooth was fixed by the crown axle. The crown axle was molded with the crown on one end and touched a spring form on the other end by means of a disc. The other end of the spring was in contact with a disc that is con-
FIGURE 6. The digital read-out strain gauge indicator used to check the calibration procedure and the cycle counter.

FIGURE 7. The gold crown to be tested is secured in the holding cylinder opposing the antagonistic fixed gold crown (between the bearings). Aluminum cams are on both sides of the test crown to direct the chewing motion.

During testing, running water was used to avoid overheating the crowns caused by friction between the contacting surfaces, which might affect the physical properties of the screws.

The chewing machine allowed contact of the palatal inclines of maxillary (fixed crown) buccal cusps with the buccal inclines of the mandibular (test crowns) buccal supporting cusps and the palatal inclines of the maxillary (fixed crown) palatal cusps with the buccal inclines of the mandibular (test crowns) lingual cusps. Contact between the buccal inclines of the maxillary (fixed crown) palatal cusps and the lingual inclines of the mandibular (test crown) buccal cusps was also reproduced. Contact between the palatal inclines of the maxillary (fixed crown) buccal cusp with the buccal inclines (test crowns) of the mandibular lingual cusps was also simulated (Figures 8A and B through 11A and B).

Testing procedure

The abutment and flat-headed gold screws were tightened according to the recommended torque values. To account for reduced torque due to the settling effect, the screws were again tightened to the same initial torque after 10 minutes. The torque required to loosen the screws was measured 2 minutes later using the torque gauge. This measurement was used to compare the torque required to loosen the screws before loading as compared with that required after subjecting the crowns to known loads.

The 4 different groups were then mounted on the holding cylinders of the simulated chewing machine. The cylinders were marked A, B, C, and D. Each assembly was randomly placed in a different cylinder during each testing cycle.

The position of each crown in relation to the opposing gold tooth was adjusted to simulate intercuspation of antagonistic molars. To ensure that the force applied was the same on all samples, the blocks were adjusted in an up-and-down position using the verti-
The crown samples were rotated back and forth within the rotating table using the switch button designed for calibration, which produced both clockwise and counter clockwise motion as desired. Rouge and chloroform were used to check the consistency of the gliding motion on the inclines of all crowns. The cams were then tightened and their positions were indexed. The crowns were subjected to 16660 cycles over 5.5 hours under 6 kg of load.

To account for the presence of 2 screws within groups 2 and 4, the implants were numbered from 1 to 6 (group 1 = implant 1; group 2 = implants 2 and 3, where 2 represents the mesial side and 3 the distal side of the test crown; group 3 = implant 4; and group 4 = implants 5 and 6, where 5 represents the mesial side and 6 the distal side of the test crown). The untightening torque was measured for the gold screws in the different groups before and after loading at 4 different locations for 8 cycles on the simulated chewing machine.
Results

Using "change scores" (Table 1), a 3-way analysis of variance (implant, location, and cycle) indicated that there was no significant difference between cycle or location. Data from location and cycles were pooled. A 1-way analysis of variance indicated a significant difference (Table 2; $P < .001$) among implants. Pairwise multiple comparison tests using the Scheffe test were carried out on mean change scores, with $\alpha = .05$ (Table 3). Implant 4 (group 3) was significantly different from the other groups, which were not significantly different from each other.

Discussion

All of the prosthetic gold screws tested were tightened to 10 N-cm according to the manufacturers’ instructions. The untightening torque of the screws in the different groups tested was about 2 N to 3 N less than the tightening torque. These observations correspond to the findings of Shigely and Mischke\textsuperscript{22} of a 2% to 10% reduction in preload within the first few seconds or minutes after tightening as a result of the settling effect (embedment relaxation). To reduce the settling effect, the screws were retightened after 10 minutes following the protocol suggested by Dixon et al\textsuperscript{33} and Breeding et al.\textsuperscript{34} Although the untightening torque after subjecting the crowns to simulated function was less than the untightening torque before loading for most of the screws, the difference was insignificant when using 1-way analysis of variance to describe the remaining groups (1, 2, 3, 5, and 6).

A study by Murphy\textsuperscript{35} showed that the teeth contact only 5.9% of the time during a mastication cycle. Outwaite et al\textsuperscript{36} estimated that 1 million cycles of loading was equivalent to 5 years of heavy wear in the mouth. Using this estimate, Breeding et al\textsuperscript{34} estimated that a month of intraoral loading resulting from mastication would equal 16,667 cycles.
Untightening torque after simulated function

The finding that a wide-diameter implant with a wide occlusal table resulted in a loose screw on all of the postload measurements is of significance. When removing the wide-diameter sample (group 3) from the remaining samples, there was no significant difference in the untightening torque among the test specimens.

The use of 2 implants to restore a molar tooth more closely mimics the anatomy of the roots being replaced and doubles the surface anchorage area. This applies to the implant-supported narrow occlusal table restoration design and the 2-implant-supported wide occlusal table restoration design.

The finding that the crowns supported by 2 implants exhibited untightening torque of prosthetic screws comparable with the untightening torque before loading supports the assumption that doubling the implants reduces the chances of rotational forces developing, which consequently reduces the likelihood of gold screw loosening.10

It has been suggested that 2 implants offer the advantage of eliminating mesiodistal bending and is strongest, yet not as efficient, in eliminating lateral bending forces. Lateral bending forces are often due to excursive contacts.18 The results of this study, however, demonstrated that the 2-implant design favorably withstood both mesiodistal and buccolingual bending. Although the untightening torque for crowns with narrow occlusal tables supported by single implants compared favorably with the untightening torque before loading, 2 loose screws were observed during the testing cycles. The screws in the wide-body implants were loose on all occasions. These findings agree with the comparative study by Balshi et al in which molars supported by 2 implants exhibited fewer complications as compared with molars supported by 1 implant.

Prostheses mobility and screw loosening were the most frequent complications associated with 1-implant molar restorations. The findings are also in agreement with the study of Bahat et al in which restorations supported with 1 implant had a higher failure rate as compared with restorations supported by 2 implants.

Buccolingual width

As the results of this study demonstrated that the buccolingual width is not as critical when dealing with 2 standard implants as compared with 1 wide-diameter implant, narrowing the occlusal table should be considered for wide-body implants. Reducing the buccolingual width may require selecting a different occlusal scheme, such as a cross-bite relationship or lingualized occlusion, to reduce the bending moments on the implant and associated structures.

During mastication, the entire occlusal surface of the tooth is involved both directly and indirectly.37,38 In this study, the inner inclines of the lower molar samples, as well as the outer inclines of the buccal cusps, were involved. Although the outer inclines of the buccal inclines are not directly involved in the process of mastication, they are the functional inclines in lateral excursions when a posterior scheme of occlusion is adopted (ie, group function). If a canine-protected scheme of occlusion is adopted, or the tooth is free in excursions, gliding against these inclines is a concern in patients with parafunctional habits.

Clinical implications and significance

The prosthetic designs and materials used to restore missing molars in this study might not be the treatment of choice in every restorative situation. The implications of the study, however, do apply to most treatment options. There are many factors, other than the restorative preference of the dentist, that play a critical role in determining the location and number of implants used. Anatomy, availability of mesiodistal space, and quality and quantity of bone are some of these factors. According to the results of this study, given the same conditions, crowns supported by 2 implants showed more favorable results and suggest the use of 2 implants to restore missing molars whenever possible. If a single implant is to be used, special consideration should be given to the occlusion and the width of the occlusal table, particularly when dealing with patients with heavy masticatory forces and/or parafunctional habits.

Although the problem of screw loosening and fracture might seem a nuisance, it could be a warning sign to a more serious problem, such as overload. If the problem is not addressed, more serious and nonretrievable complications might arise. In addition, repair and maintenance visits can be time consuming and frustrating to both the patient and the dentist.

Since the consistency and hardness of food decreases during the masticatory process and is difficult to reproduce for testing purposes, the chewing machine was fabricated to provide a constant profile. The relatively small anteroposterior movement of the jaw during chewing is eliminated, thus converting the 3-dimensional motion of the jaw into a 2-dimensional motion.

In a prospective study by Walton et al on the maintenance of implant restorations in private practice, screw loosening and fractures constituted 24% of the complications.

Limitations of the study

Being an in vitro study, reproducing actual mandibular movements in 3 dimensions is not possible. The dental literature is equivocal when considering tooth contact during mastication.15 It is estimated that the teeth contact 60% of the time during the grinding phase.39 The forces of mastication are not constant during masticatory cycles, but tend to vary depending on the mandibular position and food consistency.

Although it is recognized that a hydraulic machine with a feedback ser-
vocontroller would be the best option, due to cost considerations a simulated chewing machine was designed to generate loads through deformation of a coil spring of known stiffness by means of a rotating cam. There are many studies in the dental literature that have used machines of different designs to simulate masticatory function. The chewing machine, custom designed for and used in this study, tested the motion of 2 antagonistic teeth against each other, which resembles a natural situation.

It would have been preferable to change the gold crowns after every cycle. Due to economic factors, this was not possible. It would also have been preferable to change the abutment screws and use different sets of implants after each cycle. Again, the cost was prohibitive.

Many products, components, and techniques have been suggested for maintaining a tight screw connection; however, none have completely eliminated the problem.

Wide-diameter implants with an enlarged implant shoulder area are claimed to provide more primary surface for the abutment-implant interface, increased prosthesis stability, and strength to resist lateral bending. A wide platform implant might be a more attractive alternative when replacing a molar by a single implant.

Because of the small sample size, the nonnormality of the data, and the heterogeneity of variances, a nonparametric analysis of variance (Kruskal-Wallis) on rank sums was carried out on change scores. An $X^2$ value of 22.81 with 5 $df$ indicated a significant difference ($P < .001$) among the implants. Pairwise multiple comparison tests, controlling for experiment-wise type I error, were carried out on the mean ranks of the screws in each group to determine which implant groups were significantly different from each other. Group 3 was significantly different from group 2 (implants 2 and 3) and from group 4 (implant 5), but not from group 1 (implant 1) and group 4 (implant 6). Using this parametric analysis, group 3 (a wide crown supported by one 5-mm–diameter implant), group 1 (a narrow crown supported by one 5-mm–diameter implant), and group 4 (a wide crown supported by 2 standard 3.75-mm–diameter implants) were not significantly different from each other. Within the parameters of this study and when using both parametric and nonparametric analyses, the single wide-diameter implant did not compare favorably with the 2-implant restorative design. Using the nonparametric test, the width of the occlusal table was not of significance when comparing groups 2 and 4. Using the parametric analysis, the narrow occlusal table compared more favorably than the wide occlusal table.

**Conclusions**

Within the parameters of this in vitro study with its limitations (see “Discussion”), the following conclusions can be drawn:

- Restoring molars with 1 wide-diameter implant can cause a higher degree of screw loosening as compared with the use of 2 conventional-diameter implants.
- Narrowing the occlusal tables of restorations can reduce the degree of screw loosening when using 1 implant to support a missing molar.
- The untightening torque of gold screws should not be affected by changing the width of the occlusal table of crowns supported by 2 implants.

**Acknowledgments**

The authors would like to express appreciation to the Royal Jordanian Scientific Society (Amman, Jordan) for their assistance with the design and fabrication of the chewing machine; Nobel Biocare for their generous donation of implant materials; Lactona/Universal for the loan of resin tooth molds; Dr John Gaughan for his statistical support; and Dr Stamatis Tzamouranis for his computer graphics.

This paper was awarded first place in the John J. Sharry Research Competition, American College of Prosthodontists Annual Session, September 18, 1998, in San Diego, Calif. It was presented before the American Academy of Implant Prosthodontics on September 22, 2000, in Lake Buena Vista, Fla. This paper was based on a thesis submitted in partial fulfillment of the requirements for Dr Bakaeen's degree of Master of Science in the Graduate School of Temple University, Philadelphia, Pa, 1998.

**References**


18. Balshi TJ, Wolfinger GJ. Two-implant supported single molar replace-


28. Misch C, Bidez M. Implant protected occlusion: a biomechanical ratio-


