Effect of implant size and shape on implant success rates: A literature review

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Understanding and using biomechanical theories that effect endosseous implant design may improve the performance of implants in varying load conditions and allow the clinician to better apply this information with potentially improved success rates. The following article presents information from English peer-reviewed journals identified by a Medline search covering the years from 1974 through 2004, and attempts to integrate information available in the dental literature and address current controversies and issues in selecting diameter, length, and shapes of dental implants. (J Prosthet Dent 2005;94:377-81.)

The application of dental implants for prosthodontic reconstruction can be traced back to ancient Egypt, where seashells were hammered into human jaw bone to replace missing teeth.[1] Although it is unknown whether these substitutes were placed ante mortem or post mortem, it illustrates the desire to create artificial substitutes for natural teeth that could be anchored in bone. Early implants with documented success were fabricated from noble or base metals shaped in either basket[2] or pin[3] designs that attempted to recreate natural roots, which could then be connected to transmucosal fixed prostheses. Failures were believed to be caused, in part, by poor biomechanics, especially poor stabilization. These implants had limited success, and mechanical and biological failures prompted dentists to create new designs that, in many instances, had no semblance to tooth morphology. The most successful designs of this type are the staple,[4] subperiosteal,[5] and blade vent[6] implants.

In the mid 1960s, orthopedic research by Branemark demonstrated the phenomenon of osseointegration, whereby a biocompatible metal could be structurally integrated into living bone at a biochemical level.[7] The application of this theory to dental implants reduced the dependence on mechanical interlocking and allowed the development of implant systems in a more versatile endosseous design.[8] Subsequently, it was realized that subtle changes in shape, length, and width of endosseous implants could influence success rates,[9] and implant manufacturers began providing implants in varying designs. The size and shape of implants have evolved to fit current surgical concepts and prosthetic design. Treatment planning of patients seeking implant-supported prostheses has become complex due to the wide variety of prosthetic options and improvements in grafting previously unrestorable sites. On selection of a particular system, dentists should consider several clinical factors, which include, but are not limited to, the site and surrounding anatomy, requirements for grafting, osseous quality, and prosthodontic design. Although implants have been used for close to a half century with great success, there are few guidelines that describe when or where to use the different types of implants available.

Understanding and using biomechanical theories that affect endosseous implant design may improve the success of these implants in various load conditions and may allow the clinician to better apply these guidelines, with an improvement in success rates. The following review of the literature attempts to integrate information presented in the dental literature and to address current controversies and issues in selecting diameter, length, and shapes of dental implants. This article reviews English peer-reviewed journals identified by a Medline search covering the years 1974 through 2004.

Implant diameter

Implant diameter is the dimension measured from the peak of the widest thread to the same point on the opposite side of the implant. The diameter measures the outside dimension of the thread. Implant diameter is not synonymous with the implant platform, which is measured at the interface of the implant connected with the abutment. Because a variety of implant widths and platforms are available, a wide-platform implant is not always coincidental with an increased diameter of the implant thread.

The length and diameter of implants were originally designed to allow the use of these implants in the average alveolar processes. Currently available implants vary in diameter from 3 to 7 mm. The requirements for implant diameter are based on both surgical and prosthetic requirements. To gain maximum stability from the cortical plates of alveolar bone, the width of implants is designed to engage as much of the buccal and lingual plates as possible. Implants used for partially edentulous or single tooth spaces should also fit into the constraints

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of adjacent natural teeth. From a biomechanical standpoint, the use of wider implants allows engagement of a maximal amount of bone, and a theoretically improved distribution of stress in the surrounding bone.[10] The use of wider components also allows for the application of higher torque in the placement of prosthetic components.[10] The use of wide implants, however, is limited by the width of the residual ridge and esthetic requirements for a natural emergence profile.

Applications of wide implants

The known advantages of using wide-diameter implants include providing more bone-to-implant contact,[11] bicortical engagement, immediate placement in failure sites, and a reduction in abutment stresses and strain.[12] A wide-diameter implant can also be used as an alternative to bone grafting in severely resorbed maxillae.[13] Histological sections of wide-diameter implants in bone show more total surface contact with bone than standard implants in standard photomicrographs made with a sonic digitizer.[14] The research does not imply that a wide-diameter implant will result in a higher percentage of bone contact; however, the increase in surface area of the implant allows for an increase in the amount of total bone contact.[14] Increasing the diameter in a 3-mm implant by 1 mm increases the surface area by 35% over the same length in overall surface.[9] More contact area provides increased initial stability and resistance to stresses.[15] It has also been shown that the crestal bone surrounding the implant is the most susceptible to occlusal loading.[15] It has been hypothesized that this functional area may be more important than overall length and diameter.[15]

Improved implant strength and resistance to fracture can be attained by increasing the diameter of implants.[16] Peri-implant stress is a significant factor for screw loosening and subsequent fracture.[17] Strain tests show that by increasing the diameter of an implant, there is a decrease in the abutment strain for a given load.[12] Implants of 6-mm diameter show the most noticeable reduction in stress values.[18] It is possible that an implant must surpass a critical diameter to yield significant reduction in peri-implant stress.[10] Wide-diameter implants may also have a more favorable distribution of masticatory forces.[10]

Increasing the surface of the platform theoretically reduces stress on any point of the osteointegrated interface on occlusal loading.[19] Since occlusal loading is implicated in crestal bone loss around the implant, it is postulated that wider implants may reduce the stress around the crestal bone and potential bone loss.[18] Initial stability of implants at the time of placement has long been considered to be important to integration at the time of surgery and uncovering.[20] Therefore, achieving primary implant stabilization is desirable to facilitate the osseointegration of dental implants.[20] Mobility of implants at the time of placement may occur, especially in poor quality bone. A variety of techniques and design modifications have been proposed to optimize primary stabilization of implants in soft, trabecular bone. Langer et al[11] proposed the use of wide-diameter implants to gain implant stability at the time of placement in jaw bone regions where low-density bone is common. The authors hypothesized that increased contact obtained with a wider implant would, theoretically, allow improved engagement of bone and reduction of initial mobility.

The use of wide-diameter implants may also enable the use of wider screws and, in turn, allow for an increased preload. Abutment screw torque recommendations as high as 45 N·cm have been suggested and may reduce screw loosening. An in vitro study was conducted to determine whether varying the preload on the implant-abutment complex would affect screw loosening under simulated loading conditions. Abutment screws in specimens were tightened to 25, 30, 35, and 40 N·cm. Cyclic loading between 1 and 26 pounds was carried out using a servo-hydraulic testing machine, with the load applied directly to the abutments. The authors reported that increasing the torque value for abutment screws above 30 N·cm was beneficial for abutment-implant stability and decreased screw loosening.[21]

Wide-diameter implants also have a significant advantage in immediate implant placement in premolar and molar regions, where the defect created by tooth extraction will result in an oversized osseous preparation. Most roots flare significantly at the crest of the alveolar bone, resulting in a defect that is widest at the area most essential for initial stability. The use of wider implants in flared sockets improves the prognosis for implant survival by engaging more crestal bone than regular or narrow-body implants.[11]

Disadvantages of wide implants

Opposition to wider implants have focused mostly on possible over-instrumentation and heat generation.[11] The use of implants less than 5.0 mm in diameter[22] has been proposed to reduce heat generated in the drilling process and subsequent bone damage. The actual heat generated and distributed by implant placement has not been determined. However, it is possible that since the increased heat generated by a larger implant is distributed over a larger osseous surface, the actual amount of heat received by each unit area of bone may be the same as with a regular or narrow-body implant. Studies have also shown that 5.0-mm-diameter implants have a higher failure rate than 3.75- or 4.0-mm implants.[23] However, the authors believed the increased failure rates were due to the fact that wide-diameter implants were often used in rescue procedures for failed implants.

Applications of narrow-diameter implants

Narrow-diameter implants were introduced for residual ridges that were too narrow for regular implants and for edentulous spaces with limited interdental width. These implants are not synonymous with mini implants, which are smaller in diameter than narrow implants and have a diameter of 2.7 mm or less.[24] The mini implant was initially developed to support transitional prostheses and has not been validated for definitive fixed prostheses. The prime indication for narrow-diameter implants is in the replacement of mandibular incisors and maxillary lateral incisors. Narrow-diameter implants are also indicated when the proposed implant site is less than 5 mm in diameter and not amenable to bone grafting or orthodontic repositioning of teeth, and in interim replacement of the adolescent or adult dentition.[25-27]

Disadvantages of narrow-diameter implants

One of the primary disadvantages of narrow-diameter implants is the reduction in resistance to occlusal loading.[18] The theoretical improvements in stress distribution and fracture resistance of wider implants may eliminate the use of narrow implants in many situations. In animal studies, however, the retention of an implant was correlated to the length of the implant and not the diameter.[28] This would suggest that narrow implants may be used in situations in which axial and tangential loading are not critical factors in biomechanics. The small-diameter implant provides an alternative for narrow or compromised recipient bone. Further study is warranted to determine the limits of narrow implants in various clinical situations.

Implant length

Implant length is the dimension from the platform to the apex of implant. It has been an axiom in implant dentistry that longer implants guarantee better success rates and prognosis. Although a linear relationship between length and success rate has not been proven, studies have shown that shorter implants have statistically lower success rates.[29] The 7-mm implant, among the shortest implant length produced by most implant companies, exhibits greater failure than all other implant lengths.[30] The relationship between implant length and survival, however, is limited. A study of fixed single-unit restorations demonstrated that a relationship between implant length and success may not exist, especially over 13 mm in length.[31] No relationship between initial mobility and implant length has been established,[32] and mechanical analyses have supported the view that increasing the implant length may only increase success rate to a certain extent.[33]

The use of short implants has not been widely recommended because it is believed that occlusal forces must be dissipated over a large implant surface area to prevent excessive stresses at the interface.[28] Finite element analysis (FEA) has shown that the occlusal forces are distributed primarily to the crestal bone, rather than evenly throughout the entire surface area of the implant interface.[33] Since masticatory forces are light and fleeting, these forces are normally well tolerated by the bone.[33] This may be a reason why implant length is not linearly related to biomechanical stability. Long-term studies show a dramatic increase in failures of implants shorter than 7 mm in length.[30] However, implants as short as 5 mm in length, with porous surface treatments, were introduced to replace possible sinus lift procedures.[34]

Bone type and cortical bone engagement may be more important factors than implant length.[35] The apparent failure of shorter implants may be due to the prevalent use of short implants in the maxillary posterior areas, which also have poorer bone quality. Surface-treated implants were introduced to overcome this failure in the area where cortical bone engagement can not be achieved.[36] It is believed that the surface contact between bone and implant is increased by these treatments.[36] Further studies of shorter implants in ideal bone are required to define the limitations of short implants in prosthodontic reconstruction.

Implant shape

The shapes of dental implants have varied from traditional root forms to blade and subperiosteal designs.[37] The shape of dental implants has been one of the most contested aspects of design among the endosseous systems and may have an effect on implant biomechanics.[38] Most current implants systems are available as solid or hollow screws or cylinders. Some implant manufacturers provide implants in both shapes and recommend their use in different types of bone. Among screw-type designs, considerable modification has been made to the crestal and apical portion of the implant to increase self-tapping and decrease heat generation. Other designs have been developed to imitate root anatomy and incorporate a stepped cylindrical design, analogous to the tooth root at both cervical and apical ends. These stepped cylindrical implants show more even stress dissipation compared to cylindrical or tapered implants[39] and improved loading of the crestal bone supporting of the alveolar bone from the root analog shape of the implants.[39]

In one study, screw-shaped implants provided the greatest retention immediately after implant placement.[40] To enhance initial stability and increase surface contact, most implant forms have been developed as a serrated thread.[41,42] It is believed that thread geometry has a significant, positive effect on implant biomechanics.[41,42] Even though a rectangular shape is not a favorable shape for implant surgery, it may prove to be more stable and result in better stress distribution after osseointegration.[41] Stress distribution along the implant should be even and minimal to avoid possible complications.[41] Pitch, the number of threads per unit length, is an important factor in implant design. Increased pitch and increased depth between individual threads allows for improved contact area between bone and implant, and may modify the biomechanical properties of screw-shaped implants.[9] The effect of implant shape and size on the stress distribution around implants was examined in studies using a 3-dimensional FEA. The results demonstrated that implant root shape has more influence on stress distribution in the supporting bone around each implant than implant size.[42]

SUMMARY

The increased availability of implants in varying sizes and shapes often makes selection of the most appropriate implant design confusing. This review presents the current status of implant literature related to implant diameter, length, and shape. The understanding of how these variables may affect implant success in varying qualities and quantities of bone allows the clinician to more accurately assess the potential success of an implant in a particular situation.

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Noteworthy Abstracts of the Current Literature

Onset and duration periods of articaine and lidocaine on maxillary infiltration

Costa CG, Tortamano IP, Rocha RG, Francischone CE, Tortamano N. Quintessence Int 2005;36:197-201.

Objectives: The aim of this study was to compare the onset and duration of pulpal anesthesia by maxillary infiltration using 2% lidocaine with 1:100,000 epinephrine, 4% articaine with 1:200,000 epinephrine, and 4% articaine with 1:100,000 epinephrine.
Method and Materials: Twenty healthy patients randomly received 1.8 mL of one of the three local anesthetics during operative dentistry procedures of low complexity on three maxillary posterior teeth. Onset and duration were determined using an electric pulp tester.
Results: The mean values for pulpal onset were 2.8, 1.6, and 1.4 minutes and for pulpal duration were 39.2, 56.7, and 66.3 minutes, respectively, for 2% lidocaine with 1:100,000 epinephrine, 4% articaine with 1:200,000 epinephrine, and 4% articaine with 1:100,000 epinephrine. Statistical analysis by the Kruskal-Wallis nonparametric test showed significant differences with better results (shorter onset and longer duration periods) for both articaine solutions compared with the lidocaine solution. Although 4% articaine with 1:100,000 epinephrine clinically presented the shortest onset and the longest duration periods, there was no statistically significant difference between the articaine solutions.
Conclusion: Both articaine solutions produced shorter onset and longer duration of pulpal anesthesia by maxillary infiltration than the lidocaine solution did. Statistical analysis did not confirm better clinical results of 4% articaine with 1:100,000 epinephrine than with 4% articaine with 1:200,000 epinephrine.—*Reprinted with permission of Quintessence Publishing.*