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Implants

Success or failure of dental implants? A literature review with treatment considerations

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This study reviews the literature concerning the success or failure of dental implants and provides the general dentist with information to decide whether to recommend dental implant therapy to a patient. The authors conducted an extensive literature search for articles relating to dental implant failure. Meta-analyses and multi-center studies were predominant in the selection.

Predictors of dental implant success or failure were gleaned from various articles and presented in the form of text and tables. The main predictors for implant success are the quantity and quality of bone, the patient's age, the dentist's experience, location of implant placement, length of the implant, axial loading, and oral hygiene maintenance. Primary predictors of implant failure are poor bone quality, chronic periodontitis, systemic diseases, smoking, unresolved caries or infection, advanced age, implant location, short implants, acentric loading, an inadequate number of implants, parafunctional habits and absence/loss of implant integration with hard and soft tissues. Inappropriate prosthesis design also may contribute to implant failure.

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Endosseous dental implants have become a significant factor in prosthodontics and restorative dentistry since the early 1970s. Despite the many advances in techniques, materials, and implant design, the potential for clinical failure is a significant concern for both dentist and patient. Success rates of endosseous implants depend on the site of the implant, patient factors, the skill and judgment of the surgeon, and the type of implant placed. The literature suggests, in fact, that all of these factors interact and determine success or failure.

A distinction should be made at this point between implant failure (that is, loss of osseointegration) and an implant complication, such as the failure of a component of the implant system (for example, a set screw that can be repaired or replaced).[1] It should be noted that loosening or fracturing a set screw often indicates that the dental implant is subject to conditions that ultimately may lead to failure.[1]

A variety of dental implants were evaluated clinically and *in vitro* (with varying degrees of success) for approximately 30 years before the almost universal acceptance and clinical success of endosseous tooth root implants. For many years, subperiosteal implants were used successfully for the edentulous ridge where there was significant ridge resorption but these devices no longer are favored.[2] The significant surgical procedures and the extensive laboratory fabrication requirements for implant and superstructure castings are major disadvantages.[2]

Endosseous dental implants, which also are known as *intraosseous* and *endosteal implants*, have been developed and refined continuously since the very early designs of Chercheve in 1960.[3-6] Blade vents were the most successful devices prior to the evolution of the tooth root implant.[2] The clinical success of blade vents was dependent upon careful patient selection, availability of significant amounts of cortical bone, and highly skilled surgeons. However, subsequent restorative treatment of the implant may have affected clinical outcomes so that blade vents exhibited varying degrees of success.

One of the early pioneers in the field of dental implants, Schroeder, worked with a company manufacturing Swiss watch components in the 1960s and 1970s to develop a hollow-basket titanium implant.[7] The use of titanium and Schroeder's concept of functional ankylosis (later termed *osseointegration*) are thought to have led to the well-established procedure of simple, one-step implant surgery that is preferred at present.[7] Endosseous implants were accepted even more widely with the development of the single tooth root implant by Branemark.[8]

In a detailed clinical study, Branemark reported success rates of 70% and more in the maxilla and 75% and higher for the mandible.[9] At present, survival rates of endosseous root-form dental implants range from 85% for fixed prosthodontics to 95% and higher for single implants and removable prostheses.[1,9] Ongoing research provides valuable information for improving materials and techniques. As a result, Misch recently suggested revising the criterion for a 5-year success rate from 75% (the criterion established in 1978) to 90%, with a success rate of 85% for 10 years.[10]

The literature appears to be undecided in specifying the criteria for success or failure with implants. Some authors maintain that a successful implant is characterized primarily by the absence of pain, combined with rigid fixation.[10] Others cite more specific criteria, such as probing depth of less than 6.0 mm, bone loss that is less than one-third of the crestal height, a minimal bleeding index, less than two weeks of peri-implantitis, and no radiolucency in the adjacent bone.[1,10-13]

A variety of factors can precipitate failure of an implant, including occlusal overloading, preoperative or postoperative infection, and placement in bone of inadequate quality or quantity. Other causative or precipitating factors are the patient's overall health, oral hygiene, and caries susceptibility, in addition to the technique and experience of the operator.

The most common patient complaints indicative of implant problems are pain and/or postoperative infection. Indicators of implant failure include a horizontal mobility greater than 1.0 mm, any clinically observed vertical movement, rapid progressive bone loss and/or pain during percussion or function, and infection.[1,10,11,12,14]

This article provides an overview of the clinical use of dental implants. The literature pertaining to the criteria for success or failure with dental implants and the factors that determine these outcomes are reviewed critically. Finally, a summary of the factors predisposing implants to failure and the factors that contribute to implant success is provided.

Patient factors in dental implantology

Patients elect to have one or more implants for a variety of reasons. The primary reasons prompting the decision to undergo implant placement are eliminating the need for removable partial or complete dentures, esthetics, and the desire to conserve tooth structure in an otherwise caries-free mouth. Secondary (and sometimes primary) factors include financial considerations, specifically whether the patient can afford the surgery and subsequent restoration of implants. For example, the patient also must judge whether it is more cost-effective to extract an endodontically involved tooth and replace it with an implant than to perform alternative endodontic therapy involving possible crown-lengthening and/or post and core fabrication, which may result in a more guarded prognosis.

The clinician will incorporate any or all of the above criteria when providing recommendations and advice to the patient considering implant placement. The dentist also must consider a variety of other patient-dependent criteria when deciding to undertake implant therapy. In particular, clinical considerations, such as bone quality and quantity, oral and general health, and the patient's oral habits, are pre-eminent in the decision process. Clearly, systemic diseases may have an adverse impact upon the prognosis of oral implants, especially autoimmune diseases and chronic oral diseases such as erosive lichen planus, Sjogren's syndrome, leukoplakia, stomatitis, aphthous ulceration, lupus, and diabetes mellitus.[1,10,11,13,14-16]

Bone quality

Bone quality and quantity are essential considerations in implant success.[12,17] Bone quality has been classified into four types.[18] Type I bone is comprised of homogeneous, compact bone throughout the entire jaw, Type II bone has a core of dense trabecular bone surrounded by a thick layer of compact bone, Type III bone has only a thin layer of cortical bone surrounding a core of dense trabecular bone, and Type IV bone has a core of low-density trabecular bone of poor strength encased in thin cortical bone. Using the above hierarchy, Types I and II promise the most successful implants.

Various studies report that the maxilla (where the bone is less dense) and mandibles that have suffered severe resorption produce the most implant failures.[12,17,19] Some authors believe bone density to be the most significant factor, while others suggest that the combination of volume and density is a better predictor of implant success.[20] Low bone volume combined with soft bone quality (that is, Type IV in the above classification) increases the incidence of implant failure.[21]

Systemic diseases

Patients with systemic diseases (most commonly uncontrolled diabetes) may experience an increased incidence of implant failure.[22] Uncontrolled diabetes mellitus can impair circulation and further reduce the chemotactic and phagocytic functions of neutrophils. As a result, circulation at the site of an implant may be compromised and the susceptibility to infection may increase.[14] Several studies in the more recent literature show no significant differences in implant failure rates between controlled diabetics and control patients without the disease.[23]

Some authors have suggested that osteoporosis is a risk factor for implant success, especially for postmenopausal women.[1,9,10,24,25] Likewise, osteopenic patients may be predisposed to adverse implant outcomes because of the reduced bone density. Patients with these two diseases may fall into the category of Type IV bone. Few clinical studies have been published on the topic and opinions conflict. El Askary et al suggested that osteoporosis has a negative effect on dental implant integration, while others note that dental implants have been placed successfully in patients suffering from osteoporosis in the lumbar spine and hip.[1,24,25] Overall, it appears that the visual assessment of bone density at the time of placement may be more pertinent to implant success than a radiographic or densitometric (that is, a peripheral dual-energy x-ray absorptiometry, also known as *pDEXA*) diagnosis of osteoporosis.[26]

It has been suggested that other systemic diseases, such as Sjogren's syndrome, lupus, lichen planus, immunological disorders, and malabsorption syndromes, are influencing factors in implant outcome, although no consensus has been reached to date. In fact, since decreased salivary flow (as happens with Sjogren's syndrome, for example) predisposes the patient to dental caries, implants have been suggested as the treatment of choice for such cases.[15]

Irradiation

When considering the advisability of placing dental implants in an irradiated jaw, three issues are predominant: xerostomia, decreased blood supply, and the possible presence of osteoradionecrosis.[1,27,28] The failure rate for implants that can be ascribed to irradiation therapy seems to be minimal but the long-term effects on bone quality are indeterminate.[29] Accordingly, it would appear advisable for the surgeon to consider sufficient postradiation healing time before proceeding with treatment. According to the literature, that healing time varies from 3.0–12 months.[1,28,30-32] Jisander et al favor longer healing periods in conjunction with hyperbaric oxygen therapy.[27] Irradiation is more of a concern in the maxilla, with reports of a 25% failure rate, compared to a 6.0% failure rate in the mandible.[16,21] As a result, irradiation therapy should not be viewed as an absolute contraindication, especially in the mandible.[15,21]

Infection

The presence of infection may have a role in implant failure. Typically, implant failures have been observed when pathology is at (or within close proximity to) the implant site (for example, placement in an infected tooth socket), adjacent to an undiagnosed endodontically involved tooth, adjacent to an existing lesion (such as a cyst), or when periodontitis is present.[33,34] Immediate implant placement (that is, an implant placed into a fresh socket after tooth removal) may have a poor prognosis if extraction was necessitated by infection or perio-dontal disease.[10,35] In such situations, the adverse outcome may be the result of contamination of the implant by bacteria from the site of the implant or persistent chronic infection after the implant is placed. Heydenrijk et al determined that the microflora of the mouth prior to the placement of a dental implant determines the flora in the peri-implant area.[36] Stabile implants usually reflect the flora of periodontally healthy patients while the flora of peri-implantitus lesions usually resembles periodontitis.[36] Thorough debridement and lavage of the implant site, together with pre- and postoperative antibiotic therapy (in addition to the postsurgical use of chlorhexidine rinse or gel), may eliminate bacterial contamination, allowing the host to activate the healing process and promote success of the implant.[21,37-40]

Most authors agree that chronic periodontitis predisposes the patient to implant failure.[1,13,22,36,41] It appears that endodontically compromised teeth have a higher success rate than periodontally involved teeth when such teeth must be replaced.[42] Typically, patients with perio-dontal disease have a lower survival rate for dental implants and an increased incidence of complications compared to patients who lose their teeth due to conditions such as trauma and dental caries.[35,41,43]

The risk of cross-contamination from periodontally involved sites to implant locations appears to be significant.[1] This observation has been corroborated by cross-sectional microbial studies of failing implants whose microbial profiles were similar to those of pathological periodontal pickets, especially Gram-negative anaerobic rods, which are no longer detectable when edentulous.[26,36,44]

Ideally, in the presence of infection, placement of the implant will be delayed.[10] However, if delayed placement is not possible, the previously suggested alternative procedure of preoperative antibiotic therapy—including antibiotic lavage of the site, hand instrumentation of the implant site to remove affected bone, and postoperative antibiotic coverage in combination with the daily use of chlorhexidine gel during the entire healing period—may improve the clinical outcome, provided there is no active suppuration at the time of implant placement.[40,42,45]

Because implant survival is highly susceptible to bacterial infiltration, unresolved or undiagnosed endodontic lesions within the vicinity of the implant site pose a threat during the critical initial phase of osseointegration.[1,46] It appears that bacteria migrating from endodontic lesions challenge the host resistance and the fragile bony integration process. This situation can be averted by examining adjacent teeth radiographically prior to implant surgery to ensure that an unbroken periodontal ligament space exists around all remaining teeth. At that point, appropriate endodontic treatment and antibiotic therapy can be undertaken, allowing a suitable time for healing.

Oral lesions

Cysts are an uncommon but still important contraindication for implant placement and one that can easily be avoided by radiological examination. Changes in the cyst's status may result in bone loss and increase the risk of the implant becoming loose and nonfunctional.[1] As a result, failure may not be immediate but it may be inevitable for many types of bone and soft tissue cysts.

Mucosal lesions (such as severe erosive lichen planus) may lead to dental implant complications.[21] Since inflammatory processes in general can affect the osseointegration process and the long- and short-term survival of implants, erosive lichen planus (as well as other mucosal lesions) should figure prominently in case selection. Similar considerations probably apply to recurrent aphthous ulceration and stomatitis. Obviously, patients with autoimmune diseases (for example, AIDS, HIV, lupus, Crohn's disease, and pemphigus) and those receiving immunosuppressive drugs may have a poor implant prognosis. Allergic reactions also involve the immune system but the literature offers little data concerning how allergies affect the success or failure of implants. Although approximately 30% of the population has at least one allergy, the prevalence of those who actually suffer from allergy complications is only 10% or so.[47]

Untreated dental disease/ oral hygiene

Untreated dental disease nurtures the proliferation of oral bacteria; along with inadequate dental care and oral hygiene, it promotes the risk for bacterial contamination of the implant site.[1,48] Poor oral hygiene induces plaque formation and, in severe cases, the establishment of calculus and sub- and supragingival calculus deposits. The orientation of suprabony connective tissue fibers surrounding dental implants makes them particularly susceptible to plaque accumulation and bacterial attack. If the disease processes and their causes are not eliminated, the initiation of inflammatory processes due to bacterial ingress, plaque accumulation, and/or calculus formation ultimately leads to implant failure.

Age and gender

The impact of age and gender on implant failure is unclear. Some authors believe that there is an increased risk of failure for patients over 60.[22,49] Others suggest that age has a minor effect and is noncontributory to dental implant failure.[50,51] With advancing age, changes do occur in the mineral composition of bone, collagen, and bone proteins and fractures may take longer to heal in older patients.[15,52] As a result, older patients may require a longer period of healing following dental implant placement and before loading.

Authors disagree on the impact and the tendency of postmenopausal women to develop some form of osteoporosis or osteopenia.[1,15] The current thought is that postmenopausal estrogen status is a concern in the maxilla only.[19,53-55]

Oral habits

According to the literature, the most common patient habits that adversely affect dental implants are bruxing and smoking, although parafunctional activities (such as chewing ice and nibbling on hard objects) may cause premature implant failure.[1] Understandably, habitual bruxing increases the horizontal stress on implants; even aggressive tongue thrusting may cause problems with anterior implants.[12,56]

For natural teeth, optimal loading occurs along the long axis of the tooth; horizontal or shearing forces are the most destructive. Bruxing is not a positive force even for natural teeth because the dental implant is osseointegrated (that is, anchored into the mandible or maxilla by the bone itself). As a result, the implant does not have the ligaments that anchor natural teeth within their sockets. Loads transmitted by the implant to surrounding bone under asymmetric loading may induce osteoclasis, without the corresponding osteoblastic activity resulting from periodontal fibers (for example, when bone remodels during orthodontic therapy). As a result, horizontal/shearing forces on implants can be just as destructive (and possibly even more so) as those

Table 1. Clinician-dependent factors.

Case selection
Site selection
Implant design
Implant number/spacing
Surgical technique
One- or two-stage policy
Premature loading
Design of the prosthesis
Commitment to recall protocol

that occur to natural teeth, since the applied force may not translate into the kind of tension that can cause bone deposition when a periodontal membrane is present. Based on limited data, clinical opinion suggests that occlusal forces should be directed along the long axis of the implant during restoration, typically by anterior or canine guidance.[57] Reducing the size of the occlusal table of the prosthesis and increasing the length and/or width of the dental implant also may reduce the effects of asymmetrical implant loading and the similar stresses of the bruxing patient.

Smoking is an important factor in the failure of dental implants.[1,12,16,21,48,49,53,55,58-60] Some authors have found that smoking increases the risk of dental implant failure by a factor of 2.5.[61,62] In a 2002 study (n = 2,614), there was no significant difference in implant survival between smokers and nonsmokers.[63] The cause of the increased failure rate is uncertain but anoxia of the oral cavity and/or increased plaque formation and tar deposits due to smoking may be significant contributors. The patient and dentist must consider these biologic and human variables before proceeding with dental implant therapy.

Clinician-dependent factors of implant success/failure

Many factors that contribute to the success or failure of an implant are beyond the realm of the clinician's control but nevertheless must play a part in guiding his or her judgment as to the practicality of implant therapy. There are other variables to consider that *are* within the control of the clinician and relate strongly to the success or failure of dental implant placement (see Table 1). The experience and surgical skill of the clinician play a significant role in terms of the success or failure of dental implants.

Before beginning any dental implant case, the experienced clinician will conduct a thorough dental and medical history review. The decision to continue with dental implant therapy will be made based on these findings.

Site selection

Site selection involves considering bone quality and quantity, the forces of mastication to which the implant will be subjected, and its proximity to existing or likely endodontic therapy. The dentist must have the experience to categorize what type of bone exists for the patient in question. At that point, decisions can be made as to what type of implant (for example, the length and width) to employ or whether to avoid implant surgery altogether. Design and surface finish are important considerations that obviously depend on the personal preference of the surgeon placing the implant.

The literature suggests that bone grafting can affect osseointegration of dental implants.[15,64,65] Bone *grafting* (also known as bone *augmentation*) often is undertaken when the bone at the intended implant site is inadequate for supporting the implant. If the need for augmentation arises from bone loss due to periodontal disease, infection, or osteoporosis, it is possible that these conditions will affect the successful integration of the graft. The biologic elements of a sinus (for example, bacteria, pressure, allergy implications) must be considered when the size of the maxillary sinus makes a graft necessary.

In addition, timing the placement of dental implants in grafted bone is critical. Grafted bone must have time to integrate and mature to a highly organized structure.[10,65,66] Immature bone cannot be expected to withstand the torque inherent in dental implants while its replacement lamellar bone takes time (6–12 months) to evolve. By contrast, lamellar bone has a more organized structure, providing greater implant-to-bone contact and offering a better prognosis.

Current opinion suggests that the grafted bone should be monitored carefully and should not be loaded before it has integrated completely with the recipient site. Bone grafting can be predictable, provided that the implant site has adequate blood supply and there is no micromovement of the placed implant.[10] The reported success rate for implants placed in grafted bone has ranged from 77–85%.[29] By contrast, implants placed in mature ungrafted bone have a success rate of 95% or more.[10]

When determining the optimum site for an implant, one also must consider the occlusal forces to which the implant may be subjected. As mentioned previously, implants lack a periodontal ligament; as a result, the osseointegrated bone does not receive all of the possible benefits that natural teeth experience from the stresses of mastication. This was confirmed in a limited study by Skalak, in which a tooth model was subjected to nonaxial loading and showed uniform stress distribution in the supporting bone, with low stress concentration in the supporting bone around the tooth neck.[68] By contrast, the implant model showed stress concentration in the supporting bone around the implant neck, especially in the buccal area. In addition, shear loading generated higher stresses than axial forces at the implant neck, suggesting that shear forces may be more damaging to the bone surrounding dental implants than when the same forces are present with a natural tooth. Consequently, the restoration (and the angle of implant placement) should be designed carefully to ensure that the occlusal forces assumed by the restored implant are directed along its long axis and are well-distributed, especially in the case of multiple units. Forces along the long axis of implants and natural teeth are the most likely to be tolerated, whereas shearing forces are the least acceptable. Sites that are more posterior will be subjected to greater occlusal forces, since they are closer to the fulcrum of the mandible.

Most authors agree that mandibular implants have a greater chance for success than those placed in the maxilla. Goodacre cited mean failure rates of 10% for complete dentures in the maxilla and 3.0% in the mandible.[16] For overdentures, the mean failure rate in the maxilla was 19%, compared to 4.0% for the mandible.[16] Fixed partial dentures and single crowns showed little difference between arches (6.0% for the maxillary arch and 3.0% for the mandibular arch). A 2000 report by Snauwaert et al agreed and postulated the difference in bone quality as the reason for the difference in success.[19]

A clinician may consider an overdenture in the maxilla because there is insufficient high-quality bone for a fixed restoration requiring more implants.

Implant design

Certain design elements appear to influence the success or failure of an osseous implant, including length, diameter, surface characteristics, and core characteristics. Implant length depends entirely upon the amount of available bone. Dental implants are available in lengths ranging from 7.0–20 mm, although common usage ranges from 10–16 mm.[10] Many studies suggest that longer implants result in a higher success rate, possibly because the increased length of the bone implant interfacial contact increases the potential for greater mechanical resistance to masticatory forces, another important factor in success.[1,19,64,69] Naert et al have suggested that the use of longer implants implies that there is more available bone (that is, less prior resorption) and a lowered predisposition for failure as a result.[64] By contrast, shorter implants with their lower bone-to-implant contact, may exhibit less resistance to occlusal forces, thereby predisposing them to early failure.[1] It should be noted that implants longer than 18 mm also may be predisposed to failure, possibly because of the tendency for the bone to be overheated when such a deep site is prepared.[19]

Implant diameter also contributes to the amount of bone-to-implant contact and to the attendant resistance to occlusal forces, since the circumference of the implant increases with the diameter (see Table 2). Increasing the diameter for a given length of implant with the same design and thread characteristics increases the nominal surface area markedly, to the extent that the amount of bone surface contacted by the dental implant increases with a concomitant increase in the resistance to occlusal forces. A thread surface has an even greater surface area than a smooth cylinder.

Table 2. The increase in surface area with diameter for an implant 12.5 mm in length.

Diameter (in mm)	Circumference (in mm)	Surface area (mm^2)	Increase (%)
3.00	18.85	235.62	Not applicable
3.75	23.56	294.52	25
5.00	31.42	392.70	66.7
7.50	47.12	589.05	150

The sulcular tissue and epithelial junction that surrounds an implant is similar but not identical to that of a natural tooth. With implants, the tissue attachments are different from natural teeth but the concept of biological width is still relevant. The biological width of natural teeth is the separation between the depth of the sulcus and the crest of the alveolar bone.[10] The presence of bacteria around a tooth or implant is inevitable to some degree. A healthy distance (2.0–3.0 mm) must be maintained between the implant and the crestal bone to minimize both the inflammatory response to bacteria in the soft tissue that surrounds the implant and the eventual apical migration of the bone.[10] The selection of implant dimensions (that is, diameter and length) depends on the width and depth of bone into which the implant is to be placed. The crestal bone usually remodels 0.5–1.0 mm below the ridge crest shortly after implant placement.[10] There must be sufficient bone at the implant site to accommodate the selected implant; at the same time, the ensuing bone resorption and a proper biological width after implant placement also must be considered.

It has been suggested that stress levels for a given applied load are reduced on longer implants because of the greater surface area.[10] As a result, the bone may experience less resorption and may be less prone to pathological complications following implant placement and entry into service. However, Misch has suggested that a large biological width allows dentists to place longer implants, with less risk when the top of the implant is placed within 2.0 mm of the bone crest.[70]

Implant spacing/number

Preserving an adequate blood supply to the bone is critical to dental implant success; therefore, it is essential to maintain adequate separation between implants and natural teeth.[10] In contradistinction to this separation is the need to maximize the number of implants that are placed to support a prosthesis, so that the occlusal forces will be distributed over as great an area as possible. When designing fixed prostheses, it generally is accepted that more implants are better than fewer. Implant failures are most prevalent in bridges supported by two implants.[12,19,21] With three or more implants, the implants can be positioned in a stepped fashion, allowing better stress distribution due to tripodization.[66,71]

In general, there should be a minimum separation of 3.0 mm between a natural tooth and an implant to preserve the blood supply to the natural tooth's periodontal ligament.[10] The clinical evidence suggests that implants should be spaced 4.0–7.0 mm apart to avoid bone necrosis.[1,10]

Surgical technique

Many authors consider surgical trauma and/or limited surgical experience to be one of the most important causative factors in early implant failure.[1,13,49] Among surgeons who have placed fewer than 50 implants, early failure rates are twice those of surgeons who have placed more than 50 implants.[72,73] The most common iatrogenic elements related to surgical technique are listed below.

Overheating the bone during preparation of the implant site can lead to necrosis and a lack of implant osseointegration.[1,12,74,75] It generally is accepted that collagen is denatured and necrosis of bone cells occurs when bone is heated to 47°C for more than one minute.[74] A corollary to thermal bone cell damage is that interfacial formation of connective tissue may occur between the implant and the bone, ultimately leading to a loss of integration and loosening of the dental implant.[15,42,75,76]

Contributory factors to bone overheating during implant site preparation include poor irrigation of the surgical site, excessive force applied during cutting, and the use of dull or poorly designed surgical burs.[77] Oral surgeons typically apply a force of 200–500 g during tooth sectioning, using crosscut fissure and tapered and round tungsten carbide burs at a handpiece speed of 100,000 rpm.[78] This study indicated that irrigation of the bone with saline and (preferably) lactated

Ringer's solution increased cutting rates markedly, especially when the handpiece experienced higher applied loads.[79]

The literature indicates that certain general recommendations can be made concerning implant site preparation, although each surgeon has his or her own technique for such procedures. The applied pressure/load on the handpiece clearly must not be so high as to stall the rotating bur but obviously should not be so light that it generates only heat. Excessive cutting speeds or pressures during drilling may prevent the coolant/irrigant from accessing the surgical site adequately and may affect bone cutting detrimentally, in terms of both heat generation and cutting efficiency. Cutting rates should be approximately 0.5–1.0 mm/5.0 seconds, with copious saline irrigation used to remove chips as they are generated. Using a pilot drill (for example, a No. 2 round bur) for initial penetration allows the surgeon to evaluate bone density and thickness and provides an initial check on the direction of implant placement. Thereafter, increasing drill diameter gradually will facilitate bone penetration by reducing the required applied force as well as the heat transmitted to bone.[10] Additionally, slower bur speeds, sharp new burs, and a graded series of bur sizes all contribute to reduced heat generation during implant site preparation, increasing a favorable prognosis for implant integration.[1]

Time of implant loading

Loading implants too rapidly is one of the most common causes of dental implant failure.[10,13,59] As discussed previously, the lack of mechanoreceptors associated with dental implants compromises a patient's awareness of heavy forces; if preventive measures are not taken, this compromise may permit premature loading of implants before osseointegration is complete. If loading does occur, the micromotion sustained by the implant may inhibit bone growth, resulting in deposition of fibrous tissue repair and eventual loosening of the dental implant.[16,44,80,81] Branemark advises a stress-free healing period of at least three to six months.[82]

Misch has recommended a protocol, based on observed bone density, for progressive loading of dental implants.[10] Bone types 1 and 2 often respond well to physical loading, loading progressively in two-week intervals after an initial healing time of four months, delivering the final prosthesis as early as six months after loading. Due to their density, bone types 1 and 2 have an initial bone-to-implant contact of 70–80%.[10] Type 3 bone has an initial bone-to-implant contact of only 50% and must endure a slower loading process as a result. After an initial healing stage of six months, prosthetic loading appointments should occur three weeks apart. The final prosthesis may be delivered after 10 months.[10]

Type 4 bone is the least dense and has the highest rate of implant failure. Since the initial bone-to-implant contact is merely 25%, loading is accomplished in slower time increments. After an initial healing stage of six to eight months, prosthetic loading appointments should be four weeks apart; the final prosthesis should be delivered one year after initial placement of the dental implant.[10]

Various protocols have been developed that involve immediate loading of implants, which are particularly relevant for the completely edentulous patient. For example, when a number of implants are placed in an edentulous arch, several are left submerged without loading and a proportion are restored and placed immediately into occlusion to permit delivery of a transitional prosthesis.[83] The submerged implants are allowed to osseointegrate before they are restored. The immediately loaded implants that remain functional may be incorporated into the final prosthesis; the failed implants are considered dispensable because provisions have been made to ensure other implants are available.[83] Another approach that permits immediate loading involves placing 10–13 implants and splinting them together so that the occlusal load is spread over the entire arch rather than isolated sites.[83]

Immediate restoration of an implant also is an option when the implant is placed in an esthetically important location (for example, maxillary central or maxillary lateral). In such cases, immediate restoration satisfies the esthetic needs of the patient but restricts the imposition of masticatory forces by ensuring that the restoration is out of occlusion. In general, immediate loading of implants is a viable treatment modality if the implant is adequately stable (a stability figure of more than 32 ncm has been cited).[84] Nevertheless, many clinicians adhere to the principle of allowing complete healing and osseointegration prior to implant restoration and loading.

In accordance with a stress-free healing time, a dental implant patient's diet often is modified to protect the healing implant. Chewing on the site should be discouraged until the implant is uncovered; when that occurs, progressively harder foods may be introduced. A soft initial diet of pasta and fish usually is advised, followed several weeks later by meats. Raw vegetables should not be attempted until the clinician approves them after a final evaluation.[10]

Similarly, occlusion of the prosthesis is modified to protect the site during healing and increased progressively as osseointegration occurs. Initially, there should be no occlusal contacts and only minimal contact should be added until the final restoration is delivered.[10] All parafunctional and cantilever contacts should be avoided.[10]

According to Sennerby and Roos, cases involving immediate implant loading may show low failure rates over the first five years, although failures increased in number when a longer follow-up time was observed.[21] In a 2002 report, Penarrocha et al recommended that full osseointegration should occur before dental implants are loaded, to guarantee the greatest success.[77]

Design of the prosthesis

Before the dental implants are placed, the clinician usually decides whether the prosthesis should be a removable implant-supported prosthesis (for example, an overdenture) or a fixed prosthesis. Removable prostheses require fewer implants, less maintenance, and shorter recall appointments; in addition, they can be removed at night to rest the tissues and prevent damage from nocturnal parafunctional habits.[10] An overdenture often is selected as a treatment option for esthetic reasons since it is possible to fabricate the prosthesis with flanges that substitute for lost bone, resulting in better support of facial tissue.[10] A removable device may be the treatment of choice for the completely edentulous arch, since five implants can be placed in the anterior segment (that is, anterior to the mental foramen) of the arch. They may be designed to support a prosthesis that replaces an entire compliment of teeth without the need for posterior implants.[10] Many patients object to a removable appliance, either for reasons of vanity or because they prefer a prosthesis as similar to their natural teeth as possible. Obviously in the case of a single missing tooth, a fixed prosthesis is clearly the treatment of choice, especially in the anterior region of the mouth.

When designing fixed prostheses, more implants are preferred, provided bone quality and quantity are good. Implant failures are more prevalent in bridges supported by two implants compared with those supported by three or more.[12,21,64,65] With three or more implants, positioning can be designed in a stepped fashion (as opposed to a straight line), allowing better stress distribution through tripodization.[68] Conversely, some authors believe that the increased time involved in placing multiple implants surgically may carry with it an increased risk of infection.[85] Still, dentists should avoid overloading for any full-arch or partial fixed prosthesis.[86] Some of the factors that contribute to overload include bruxing and clenching, off-axis inclination, high crown/implant ratio, and long cantilever.[19,87]

To provide a functional arch for the patient without placing implants posterior to the mental foramen, it sometimes is necessary to design a cantilevered prosthesis. From an engineering standpoint, it is difficult for a cantilever to provide centric loading along the long axis of the implant. When a cantilever design is necessary, the maximum length for posterior cantilevers should be 15 mm.[88]

Regardless of the type of device used (that is, fixed or removable), distribution of forces on the implants must be adhered to strictly, notably along the long axis of the implant.[1,12,89] This requirement can be a challenge when significant bone loss has changed the crestal width.[10] When significant bone loss requires offset positioning of the implant prosthesis for optimal esthetics, the clinician may opt for some tissue support of the prosthesis to facilitate masticatory force distribution. Implant failure is a concern if the angle of change exceeds 25 degrees, since offset loading of this type may generate shearing forces that the bone cannot tolerate.[10,90]

When an implant prosthesis replaces a long span (that is, two or three teeth), the clinician should use at least two implants to support the prosthesis independently. As the number of implants increase, the occlusal forces applied to the abutment screws decrease, as does the attendant risk of screw loosening.[10] However, a totally implant-supported prosthesis is not always possible; in those instances, a natural tooth may be used as an abutment for the prosthesis, although many authors feel that using natural teeth in combination with dental implants is contraindicated.[10,91-93] Accoding to Misch, the natural tooth in question should have a long-term prognosis of more than 10 years as well as a satisfactory pulpal status (or else it should have received root canal therapy).[94]

Table 3. Predictors of implant success or failure.

Positive factors	**Negative factors**
Bone type (Types 1 and 2)	Bone type (Types 3 and 4)
High bone volume	Low bone volume
Patient is less than 60 years old	Osteonecrosis
Clinician experience (more than 50 cases)	Patient is more than 60 years old
Mandibular placement	Limited clinician experience
Single tooth implant	Systemic diseases (for example, uncontrolled diabetes)
Implant length >8.0 mm	Auto-immune disease (for example, lupus or HIV)
Fixed partial denture with more than two implants	Chronic periodontitis
Axial loading of implant	Smoking and tobacco use
Regular postoperative recalls	Unresolved caries, endodontic lesions, frank pathology
Good oral hygiene	Maxillary placement, particularly posterior region
	Short implants (<7.0 mm)
	Acentric loading
	Inappropriate early clinical loading
	Fixed partial denture with two implants
	Bruxism and other parafunctional habits

It should be noted that combining a rigid implant with the more elastic natural tooth and its supporting periodontal ligament may subject the implant to flexural forces.[13,91,95] Although these difficulties may be minimized through nonrigid connectors, such designs appear to present a high incidence of complications.[96,97] Conversely, it has been suggested that combining implant and natural tooth support for a prosthesis may enhance patient perception of masticatory force through proprioception, reducing the chances of overload as a result.[97,98]

Commitment to patient recall

Although implant maintenance cannot be stressed enough, the dentist also must emphasize the importance of the precise recall regimen, together with meticulous oral hygiene. Like natural teeth, implants are subject to bacterial attack and possible periodontal pocket formation. The goals of implant placement are osseointegration and formation of a perimucosal seal that acts as a barrier to bacterial and chemical invasion. Failing implants have been shown to harbor increased levels of subgingival spirochetes and gingival inflammation. A wide variety of microorganisms are known to occur within the sulcus of failing implants and the detected species are significantly different from those found in periodontally diseased teeth.[99] Well-maintained implants rarely exhibit subgingival spirochetes, a possible causative agent of soft-tissue damage and impeded healing.[100,101] The microbial population that surrounds implants should be minimized or eliminated and plaque should be removed to ensure long-term success. A recent study reported that the local delivery of antibiotics such as tetracycline has a markedly beneficial effect on peri-implantitis and a potentially positive effect on clinical and microbiological parameters.[102]

The patient's oral hygiene may include

antimicrobial mouthrinses and the use of manual or mechanical interdental brushes for removing plaque between implants, especially in posterior areas.[101] Brushing with antimicrobial rinses allows the antimicrobial solution to penetrate areas that may not be accessible by rinsing alone.

Because implant failures after osseointegration result chiefly from peri-implantitis, the patient's oral hygiene regimen should be supported by a recall protocol established by the clinician.[1,86,101,103,104] Recall appointments every three months allow the clinician to monitor the implants for adjacent inflammation, plaque buildup, and any observable movement that may indicate loss of osseointegration. Periapical radiographs taken every six months for the first two years will serve to document vertical bone loss or the formation of peri-implant radiolucency.[10,103] The security of all screws is assured routinely and regularly, since loosening a screw-retained prostheses may permit an ingress of bacteria and microorganisms.

Summary

The success or failure of dental implants is influenced by many factors. When deciding whether to use implants, the dentist must pay special attention to the patient's general health, oral health, and hygiene, as well as any interfering habits. Once the decision is made, other factors must be considered, including the surgeon's level of experience and the dentist's adherence to appropriate prosthetic design principles and recall procedures. The predictors of implant success or failure are summarized in Table 3. The most critical positive factors appear to be bone type and volume, the dentist's experience, the patient's oral hygiene, implant dimensions, and placement location. The most critical negative factors appear to be poor bone quality and quantity, systemic or localized pathology, tobacco use, lack of clinician experience, short implants, and overloaded implants (that is, multiunit bridgework placed on a restricted number of implants).

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