A review of selected dental literature on evidence-based treatment planning for dental implants: Report of the Committee on Research in Fixed Prosthodontics of the Academy of Fixed Prosthodontics

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This literature review summarizes research with the aim of providing dentists with evidence-based guidelines to apply when planning treatment with osseointegrated implants. Peer-reviewed literature published in the English language between 1969 and 2003 was reviewed using Medline and hand searches. Topics reviewed include systemic host factors such as age, gender, various medical conditions, and patient habits, local host factors involving the quantity and quality of bone and soft tissue, presence of present or past infection and occlusion, prosthetic design factors, including the number and arrangement of implants, size and coatings of implants, cantilevers and connections to natural teeth, and methods to improve outcomes of implant treatment in each category. The review demonstrated that there is no systemic factor or habit that is an absolute contraindication to the placement of osseointegrated implants in the adult patient, although cessation of smoking can improve outcome significantly. The most important local patient factor for successful treatment is the quality and quantity of bone available at the implant site. Specific design criteria are provided, including guidelines for spacing of implants, size, materials, occlusion, and fit. Limitations in the current body of knowledge are identified, and directions for future research are suggested. (J Prosthet Dent 2004;92:447-62.)

In 1969, Branemark et al[1] published landmark research documenting the successful osseointegration of endosseous titanium implants. Since then, these methods for surgical placement of dental implants have had a profound influence on the practice of dentistry. Implants have become the treatment of choice in many, if not most, situations when missing teeth require replacement.[2-7] However, implants are not without potential problems. A tangible number of implants do not integrate or do not survive for long-term function.[8-11] Complications and loss of implants can be costly, both in terms of time and financial resources. Loss of integration can be troublesome, resulting in an edentulous space more difficult to restore than prior to implant placement. The ability to reliably identify patients and conditions with greater potential for failure would be valuable.

The placement of implants should not be undertaken without careful consideration of many variables, including systemic and local host factors and the design of a prosthesis. Treatment planning decisions should, whenever possible, be based on evidence-based predictions of the best long-term success. This article reviews the dental literature to provide clinically relevant guidelines for the dentist to aid in planning implant treatment. English-language peer-reviewed articles published between 1969 and 2003 were identified using Medline, as well as a hand search, and reviewed.

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This article will review implant success and failure. For this purpose, a successful implant is defined as an osseointegrated dental implant that is successfully restored and contributing to the functional success of a dental restorative treatment or one that could be used for such purposes. An implant failure is defined as a dental implant that is not fulfilling this criterion. Early failure refers to an implant that fails to osseointegrate before second-stage surgery or uncovering of the implant. Late failure refers to loss of osseointegration or mechanical failure of an implant after second-stage surgery. Most research on the success of dental implants concentrates on the first few years after placement. Research to date suggests that when implants do fail, they tend to do so soon after placement,[12] and the likelihood of failure decreases from the time of implantation through 5 years postsurgery.[13] Long-term research is needed to ascertain if there is another increase in implant failure rates occurring many years after placement surgery.

SYSTEMIC HOST FACTORS

Patient age

Most implant patients tend to be older, as there is more likelihood of tooth loss with increasing age. However, younger patients who have missing teeth and few other restored teeth would, if conditions allowed, be ideal implant candidates. While there is no evidence for a lower age limit for the process of osseous integration to be successful, osseointegrated implants act similarly to ankylosed teeth and, therefore, lack the ability of natural teeth to compensate for skeletal bone changes in growth.[14,15] While this may be acceptable in adult patients, it is a significant factor to consider in adolescent or younger patients who are still growing.[16] Possible complications of the placement of implants too early in life include the submerging of an implant into the jaw, loss of support for the implant, relocation of the implant, and potential for interference with normal growth of the jaws.[15] Also, since there is more vertical growth in the posterior regions of both the maxilla and mandible during childhood and adolescence, implants placed distal to the canines present more complications.[17]

In the mandible, an important factor to consider is the amount of rotational facial growth.[17-19] In patients with a significant rotational growth pattern, there is more growth in a posterior direction and an increased potential for posterior implants to submerge into the body of the mandible, resulting in a prosthetic infraocclusion.[17-19] In patients with less rotational growth but more anterior growth, posterior mandibular implants may interfere with the normal anterior migration of natural teeth, ultimately interfering with the development of proper occlusion.[15,19]

In the maxilla, straight vertical growth exceeds growth in any other dimension, but the alveolar process undergoes considerable changes in all dimensions throughout the growth period.[15,19,20] In addition to implant submergence, the apices of implants may become exposed in the nasal or antral cavities, and anterior implants can be lost entirely due to remodeling.[15,19] Also, the growth in the midpalatal suture area should be considered. Oesterle et al[15] discussed the possible restriction of transverse growth of the maxilla when a fixed implant-supported prosthesis is placed across the midpalatal suture in a growing patient.

With congenitally missing permanent teeth, the advantage of waiting for growth to cease must be weighed against the reduction of ridge width over time. Ostler and Kokich[21] found a 25% decrease in width of the residual ridge within 3 years of a primary molar extraction but then only 4% over the next 3 years. This loss might be better treated with ridge augmentation techniques, rather than risking the complications of placing implants too early.

While most authors concur that it is necessary to wait for the growth of the jaws to conclude before placing implants in normal healthy patients, how to assess when this occurs is not clearly established. Westwood and Duncan,[22] after a review of literature, suggest that clinical signs of growth, such as foot size and height, should be stable and the eruption of the permanent dentition should be complete. A rough estimate is 15 years old for women and 18 for men, although dental and skeletal maturation are better guidelines than the chronological age. Individual assessment by serial cephalometric radiographs, 1 year apart, is needed to confirm that growth has truly ceased.[22]

At the other end of the age spectrum, there is presently no scientifically proven contraindication for the placement of implants, based solely on increasing age.[23-25] Although the integration process itself is not compromised by increased age, older patients, theoretically, have potentially longer healing times, more systemic health factors, more problems adapting to new prostheses, and a decreased ability to maintain hygiene. Studies by Bryant and Zarb[17,26] concerning implant outcomes in older and younger patients found no contraindication to the use of implants in older patients. The quality and quantity of available bone for implant placement and the surgical technique employed are more important factors than age. However, the older the patient, the greater the likelihood of poorer local bone conditions, so care in selecting the surgical sites is prudent.

Gender

Patient gender, in the absence of any other patient differences, has not been shown to be a factor in implant failure.[27]

Diabetes

Diabetic patients show delayed wound healing,[28] increased alveolar bone loss,[28] increased periodontal disease,[29]and increased inflammatory tissue destruction,[30] all potentially complicating factors when placing implants. Also, bone and mineral metabolism are altered in diabetics,[29] possibly interfering with the integration process. However, several studies have shown success with dental implants in patients with controlled diabetes.[29,31-33] Fiorellini et al,[29] in a study of 40 patients, found lower success rates in diabetic patients, approximately 85%, but the authors concluded that this was still a reasonable treatment outcome potential. Most of the failures were in the first year after loading. Morris et al[32] studied over 650 patients with Type 2 diabetes and found only marginally more failures than with nondiabetic patients. The authors also found increased success with hydroxyapatite (HA)–coated implants and the use of chlorhexidine mouth rinses at the time of surgery. In addition, Kapur et al[34] compared diabetics who had only moderate levels of metabolic control with nondiabetic patients and also concluded that implants could be used successfully in diabetic patients. This was substantiated by Olson et al,[35] who studied diabetics with implants over a 5-year period. The authors found that the duration of diabetes had an effect on implant success. Greater failure rates were found in patients who had diabetes for longer time periods. The authors theorized that just as with the increased likelihood of other microvascular complications, such as retinopathy and neuropathy, an increasing duration of diabetes could cause microvascular disturbances that might contribute to implant complications. However, no definitive length of time associated with a diagnosis of diabetes has been established as a guideline for treatment planning.

Osteoporosis and estrogen status

Osteoporosis is the loss of bone mass and density throughout the body, including the jaws. Bone metabolism is impaired and thus, theoretically, osseous integration may be more difficult to achieve. However, established systemic osteoporosis does not imply that a jaw bone is unsuitable for osseous integration,[36-38] nor is it an absolute contraindication to implant therapy. While a correlation between systemic bone loss and the loss of jawbone density and quantity has been shown,[39] there has not been a link established between systemic osteoporosis and implant failure. Becker et al[40] quantitatively measured osteoporotic bone loss in the radius and ulna in a group of dental implant patients and found no correlation between the quantity of arm bone and implant failures. The authors suggested that visual inspection of the quality of bone at the implant site was a better indicator of implant success.

Osteoporosis frequently occurs in postmenopausal women, but Dao et al,[36] in studying the association between premenopausal and postmenopausal women and implant failure, did not find a higher failure rate for implants placed in women older than 50 as compared with women younger than 50 or between women and men older than 50. Minsk and Polson[41] also found no correlation in older women with or without hormonal replacement therapy and implant failures. Neither of these studies differentiated between maxillary and mandibular implants. August et al[42] examined jaw differences in pre- and postmenopausal women and found more failures in postmenopausal women with maxillary implants, but not mandibular implants. The authors found that postmenopausal women not taking hormone replacements had the highest failure rates. They reasoned that because osteoporosis affects trabecular bone more than cancellous bone and the maxilla has more trabecular bone content than the mandible, the maxilla is more susceptible to the effects of systemic osteoporosis. Minsk and Polson[41] studied postmenopausal women undergoing hormone replacement therapy and found that the combination of postmenopausal hormone replacement and smoking did result in more implant failures. Osteoporosis has been shown to result in loss of periodontal attachment,[43] but a similar loss of peri-implant tissue has not been established. For patients with extreme osteoporosis, it may be wise to be cautious with maxillary implant treatment planning and advise patients of the increased potential for negative effects resulting from smoking.

Cancer and cancer treatments

Patients who have undergone tumor resection in the oral region are some of the most difficult patients to restore prosthetically and those who could benefit most from the placement of endosteal dental implants. However, there are concerns about the ability of irradiated tissue to support osseous integration and the effects of systemic chemotherapy on bone quality.

Radiation treatment

The oral effects of radiation treatment include xerostomia, mucositis, hypovascularity, fibrosis, hypoxia, and most seriously, osteoradionecrosis,[44-46] all potential hindrances to implant success. August et al,[47] in a retrospective study, concluded that past tumoricidal radiation is no longer an absolute contraindication to implant placement, but reduced success rates, usually reported around 70%,[48] can be expected, and the long-term stability of implants in irradiated bone still needs further study.

To counteract the effects of radiation on bone growth and remodeling, some authors have suggested the use of hyperbaric oxygen therapy (HBO)[48,49] to improve osseous integration. HBO increases the blood-to-tissue oxygen gradient and improves the healing capacity of irradiated tissue by stimulating capillary growth and osteogenesis.[50-52] Treatment consists of breathing 100% pressurized oxygen for approximately 90 minutes for about 20 sessions presurgery and 10 postsurgery. However, many reports of successful implant placements, especially in the mandible, without HBO have demonstrated that it is not necessary for successful integration.[49,53-55] Albrektsson et al[56] suggest that without HBO therapy, implant surgery should be delayed for 12 months after radiation for optimal success with implant integration. However, the need for expediency of treatment for head and neck tumor patients to restore function, as well as a potential reduction in life expectancy for these patients, makes it difficult to delay treatment.

Weischer and Mohr[57] reported on a retrospective study that tracked irradiated patients for 9 years and also concluded that irradiation does not significantly affect osseous integration. However, the authors asserted that an important consideration was whether the definitive prosthesis was strictly implant-supported or a combination of implant- and tissue-supported. They concluded that soft tissue support should be avoided if possible, or at least minimized, due to the complications associated with poorer soft tissue healing.

Chemotherapy

Chemotherapy cancer treatment causes malnutrition of osseous tissue, xerostomia, mucosal inflammation, and other complications.[58] While implant integration during active chemotherapy cannot be supported by available data, Steiner et al[59] reported on success in 1 patient who started chemotherapy 1 month after having implants placed. Kovacs[60,61] reported on patients who had previously received courses of 3 common chemotherapeutic agents, but no radiotherapy prior to implant placement. The author concluded that there was no clinically significant detriment to the success of implants in the mandible over the study length, which averaged 3 years per patient. Research with other chemotherapeutic agents for longer periods of time and with maxillary implants is needed.

Corticosteroids

Long-term use of corticosteroids generates a systemic loss of bone mass and delayed wound healing and may modify a patient's response to bacterial infection.[62] However, there are few studies documenting the effect of corticosteroids specifically on jaw bone or on the process of osseous integration in the jaws. Fujimoto et al[63] studied osseointegrated implants in rabbits and found that systemic corticosteroids had less effect on the integration of titanium implants in the mandible than in skeletal bone. Also, even though the long-term use of steroids has not been shown to have a deleterious effect on gingiva and periodontal tissue adjacent to teeth,[64] the effect on peri-implant tissues has not been documented. At the present time it would appear that prolonged use of corticosteroids is not a contraindication to the placement of implants.[65] A more important consideration is the status of the disease process for which the corticosteroids are being administered and the prognosis for overall patient health.

Genetics and the immune system

Recent research has shown that variations in the immune system and genetic factors can predispose patients to dental disease, particularly inflammation caused by bacteria and resulting periodontal disease. Logically, some of these factors may be expected to impact implant therapy.

A study of implant failures by Kronstrom et al[66] and a previous study by the same authors on humoral immunity[67] found humoral immunity to *Bacteroides forsythus* and *Staphylococcus aureus* increased early implant failures, even in patients given antibiotics prior to implant surgery. Results suggest that patients with failing implants may be unable to mount protective serum immunoglobulin G titer levels to these pathogens. Both of the pathogens studied have been linked to dental and systemic infections. However, further study is needed to be able to predict which patients are poor implant candidates based on their systemic immunity to *B forsythus* and *S aureus*.

Nosaka et al [68] studied the calcitonin receptor gene, one of the genes responsible for bone resorption, and its effect on early buccal marginal bone loss around implants. A correlation between polymorphism of the gene and buccal marginal bone loss in the mandible, but not the maxilla, between first- and second-stage implant surgery was found. Whether this was clinically significant to the long-term success of the implants was not established.

Genetic markers associated with increased interleukin-1 (IL-1) production have been shown to be a factor in increased susceptibility to periodontal disease.[69] Salcetti et al[70] showed that patients with peri-implantitis release significantly more prostaglandin E2 and interleukin 1 compared to patients without peri-implantitis when both are exposed to the same bacterial colonization. However, Wilson and Nunn,[71] in studying the relationship between the IL-1 periodontal genotype and implant loss in 27 patients, failed to find statistically significant increases in implant failures in patients who were positive for the IL-1 genotype. The authors theorized several reasons for the results, including a lesser effect of the gene on peri-implant tissue as compared with periodontal tissue, the possibility of smoking masking the action of the gene, and the limited time period of the study not being able to demonstrate a possible increase in long-term failures.

Other diseases

There have been case reports of the successful placement of implants in patients with a wide variety of systemic conditions that could potentially affect biologic functions, particularly healing mechanisms. These diseases include scleroderma,[72] Parkinson's disease,[73] Sjogren's syndrome,[74] HIV infection,[75] multiple myeloma,[76] chronic leukemia,[58] pemphigus vulgaris,[62] and hypohidrotic ectodermal dysplasia.[77]

Rather than the specific nature of the disease process, the prognosis for a patient's long-term survival and local bone quality at the implant site are more important concerns in implant treatment planning. Also of importance is the overall health and stamina of a chronically ill patient. Patients must be able to tolerate the stressful effects of surgery and extensive restorative appointments.

The cluster phenomenon

While none of the conditions discussed above are absolute contraindications to implant therapy, a combination of risk factors might be. Ekfeldt et al[78] studied a group of implant patients who had multiple implant failures, in the hope of identifying patients at risk before treatment. The authors termed the occurrence of multiple implant failures the "cluster phenomenon." They concluded that while no one risk factor was critical, a combination of several factors such as diabetes, osteoporosis, ongoing medications, mental depression, parafunctional jaw movements, and heavy smoking habits could provide a contraindication. However, local anatomic conditions were greater predictors of success.

Weyant and Burt,[12] in a study of almost 600 patients receiving implants, found that if a patient had 1 implant failure, there was a 30% chance that they would have at least 1 other failure. These studies imply that there exists a systemic determinant of implant survival that is lacking, or a determinant of failure that is present in some patients. To date, these critical determinants of high-risk patients have not been identified or understood.

SYSTEMIC MEASURES TO IMPROVE OUTCOMES

Antibiotic premedication

The routine use of antibiotic premedication before dental surgery is not generally recommended,[79] but there is conflicting evidence in the literature regarding the benefits of premedication for implant surgery. Some studies have shown that systemic antibiotic use prior to the surgical phase of implant placement can reduce the occurrence of infection after surgery and increase the success rates of integration.[80,81] Another study found no such effect.[82] However, almost all authors suggest use of presurgical antibiotics for patients with reduced host responses, such as those with diabetes, when the surgery will be lengthy and extensive.[83] Dent et al,[81] in an analysis of 2600 implants, found that the dosage of antibiotic is important and that the guidelines suggested by the American Heart Association for prevention of bacterial endocarditis,[84] or the recommendations of Peterson,[79] were most appropriate.

Lambert,[85] in a 3-year study on the influence of smoking on implant success, showed that antibiotic use for patients who smoke is especially important. The data showed that patients who smoked and who were not given preoperative antibiotics were 3 times more likely to have implant failures. When antibiotics were used, the authors found that failure rates for smokers and nonsmokers were the same. The reason for improved outcomes after the use of antibiotics is not known, but it is theorized that a more aseptic surgical site allows better osseous integration at a cellular level.[80]

Nonsteroidal anti-inflammatory drugs (NSAIDs)

Certain NSAIDs are used in the treatment of periodontitis to slow the rate of alveolar bone loss. Jeffcoat et al[86] studied the use of a 3-month course of NSAIDs for patients receiving dental implants and reported that 100 mg of flurbiprofen taken twice daily resulted in less bone loss in the immediate postloading period. The higher level of bone was maintained for the first year after initial surgery. The authors did not establish that the increased level of bone was clinically significant for long-term implant survival.

HABITS

Smoking

Patients who smoke have an increased risk for occurrence and severity of periodontal disease.[87,88] Also, the deleterious effect of smoking on wound healing after tooth extraction is well documented.[89-91] Therefore, the negative effect of tobacco use on implant success should be expected, and indeed this is established by several studies.[92-96] Specifically, rather than affecting the process of integration, the negative effect of smoking seems to occur after second-stage surgery.[85,97] Gorman et al,[97] in a study of over 70 dental and medical history variables, in patients receiving over 2000 implants, found significantly more failures in smokers after second-stage surgery. After loading, differences between smokers and nonsmokers were not significant, but patients were not followed long-term. Success in smokers was increased by use of presurgical antibiotics and HA-coated implants. Lambert et al[85] also conducted a longitudinal study to assess the influence of smoking in a group of patients with over 2900 endosteal dental implants. The results did not indicate significant early failure after initial surgery that was expected but showed more failures after the second stage of surgery. The authors theorized that the effect of tobacco on healing after implant placement is different from that after tooth extraction because implant wounds are closed, and the intimate adaptation of the implant to the bone tissue does not allow the same magnitude of interference in healing by the vasoconstrictive nature of nicotine. Although some smaller studies[35,66] have failed to find a link between smoking and implant failures, the evidence of these larger studies is difficult to ignore.

After implants are uncovered, the soft tissues around them are adversely affected by tobacco in a manner similar to that by which periodontal tissues are adversely affected.[98] Smoking has been associated with an increased incidence of peri-implantitis (deep mucosal pockets around dental implants, inflammation of the peri-implant mucosa, and increased resorption of peri-implant bone).[13,99] After implant uncovering, smokers tend to have faster rates of peri-implant bone loss, especially in the first year, compared with nonsmokers or patients who have stopped smoking.[100] Whether this bone loss is significant for implant success has not been clearly established.

In general, smoking appears to have a greater impact for maxillary implants than for mandibular implants.[93,99,101] De Bruyn and Collaert,[93] in a retrospective study of over 200 implants, found that prior to loading, there was a difference in success rates in smokers between maxillary and mandibular implants. Maxillary success rates were adversely affected, but those in the mandible were not. Kan et al,[101] in a study of 60 patients, reported that smoking was detrimental to the success of implants placed into grafted maxillary sinuses, regardless of the amount smoked. Also, a study by Haas et al[99] found peri-implantitis significantly worse in the maxilla in smokers than in nonsmokers, but this relationship was not found in the mandible. The authors theorized that mandibular treatments tended to more likely utilize implant overdentures and that, along with protection from the tongue, the prostheses provides a physical barrier to the peri-implant tissues from the local effects of smoke. In addition, smoking is known to reduce systemic bone density,[94,102] and correspondingly, there is an increased incidence of poorer bone quality in the jaws of smokers. Smokers have significantly higher levels of Type IV bone.[92]

Bain and Moy[92] found differences between moderate to heavy smokers and lighter smokers, with increased tobacco use correlated with increased implant failure rates. The authors found that the prevalence of Type IV bone was twice as high among heavy smokers as compared with nonsmokers or even light smokers. Patients who quit smoking tend to have a reduction of the effects of smoking on implant survival,[85,102] but the length of time after cessation that is necessary for a significant improvement has not been sufficiently investigated.

In addition to the suggestions of Gorman et al[97] for use of antibiotics and HA-covered implants, success rates in smokers could be affected by the type of cover screw used. Schwartz-Arad et al[95] studied the complications of smoking in patients with implants and found a greater incidence of complications in smokers who had implants with high cover screws as opposed to those with flat cover screws. However, most of the complications did not result in failures during the length of the study.

Increasing the predictability of the success of dental implants is another reason why patients should be advised to stop smoking permanently. The protocol suggested by Bain[102] should be followed, which advises patients to cease smoking for a minimum of 1 week prior to and at least 8 weeks after implant surgery. In Bain's research with smokers who complied with this protocol, short-term implant success rates were similar to those in patients who had never smoked. However, for heavy, long-term smokers, it is less likely that bone quality will improve significantly in such a short time and patients should be informed about the reduced success rate to be expected, especially for maxillary implants.[92-96]

Parafunction

Parafunctional habits (clenching and bruxism) have been identified as concerns in implant treatment planning due to the increased pressure on the implants, resulting in possible metal fatigue and fracture[103] and possible surrounding bone loss.[104] Overload caused by either improper prosthesis design or parafunctional habits is considered one of the primary causes of late-stage implant failures.[105] However, Engel et al,[106] in a study of 379 patients who had worn implant-retained restorations for many years, found that increased occlusal wear, usually an indicator of the severity of a bruxism parafunction, had no effect on implant integration and did not result in an increased loss of bone around implants.

Rather than regarding excessive occlusal forces in patients with parafunctional habits as absolute contraindications, many authors have recommended attempting to mitigate these forces.[105,107-112] Methods suggested include educating patients about habits,[107] placing an increased number of implants,[105] placing larger implants,[108] planning the placement of implants to reduce bending overload,[103] avoiding the use of cantilevers,[109] using bruxism appliance therapy,[110] increasing time intervals during the prosthetic restoration stages to provide more opportunity for progressive loading techniques,[111] paying diligent attention to occlusal contact design,[107] and using acrylic resin teeth in the prosthesis.[112]

The oral burn syndrome

Cullen[113] reported on the deleterious effects to soft tissues around implants and other dental appliances after the ingestion of hot foods and liquids. He termed this effect the *oral burn syndrome*. Similar to the known harmful effect of overheating bone during the placement of implants,[114,115] Cullen theorized that the amount of metal in implants hastens the transfer of heat to supporting tissue and that this is a significant factor of implant complications. He suggests that patients with extensive metal dental restorations, especially patients with implants, be advised to avoid extremely high–temperature foods and drinks. This is a unique observation and warrants further research.

Addictions

Placement of dental implants in patients with addictions to drugs and alcohol would seem to be unwise due to a patient's lack of commitment to long-term health and the questionable ability to maintain implants. However, biologically, there is little evidence that chemical addictions can alter the successful integration of implants. Weyant,[13] in a 5-year study of Veterans Administration implant patients, found that abuse of alcohol was a risk factor for poor implant healing and eventual failure. However, Ekfeldt et al,[78] in a study of patients with multiple implant failures, found no histories of addiction to alcohol or drugs.

LOCAL HOST FACTORS

Hard tissue

Of necessity, there must be proper quantity and quality of bone into which dental implants are placed. The more bone in an implant site, the larger the ratio of bone to implant surface area, which increases the chances of successful integration. A larger and denser bone mass surrounding the implant may also increase postintegration resistance to forces generated by the restoration in function. Guidelines for placement of implants aim to maximize bone-to-implant contact, within the anatomical limitations present at the site to be restored.

The primary requirement is for healthy bone and secondly bone of sufficient quantity and quality to permit placement of stable implants and subsequent integration. Larger quantities of bone permit placement of longer implants. Anatomical limitations associated with the maxilla and mandible have been described by several authors.[116-118] Classification systems have been developed to help determine the feasibility and predictability of implant placement.[119-121] Systems are based upon jaw shape (degree of absorption, class A-E), as well as bone quality (amount of compact bone, class 1-4)[116] and bone density (class A-C).[120] If patients have poor bone quality and/or a lack of ridge height, grafting procedures prior to or associated with implant placement have been suggested.[122-124] Alveolar ridge width must be sufficient to permit 1.5 mm of bone on both the labial and lingual surfaces for circumferential osseointegration.[125] For implant restorations in the partially edentulous arch, 3 mm between the implant and an adjacent natural tooth is recommended to minimize the potential for damage to the supporting structures of the natural teeth.[118] Multiple grafting techniques have been described to augment residual ridge height and width for both mandible and maxilla.[126-131]

However, excessive amounts of bone may require implant placement at vertical levels that could create occlusal plane interferences in the completed restoration. Ideally, some amount of resorption in the maxilla and mandible is desirable in consideration of surgical access and prosthodontic dimensional requirements. Otherwise, lack of proper occlusal clearance may significantly compromise masticatory function, phonetics, and esthetics. The amount of interarch space necessary for a restoration has not been adequately quantified.

Also, balance between the amount of cortical and trabecular bone is required. Cortical bone is very dense and has a more limited blood supply that may delay the integration of implants. This may necessitate an extended time interval between surgical stages. The presence of too much loose trabecular bone may limit early stability of an implant and may also require a longer integration time.

When proposed implants will be too close to large nerves, 2 possible solutions are the augmentation of the ridges to permit implant placement away from the nerve tissue or transportation of the nerve itself.[118,132] However, these techniques are not without potential significant side effects, especially in the maxilla.[133-135]

Soft tissue

As with natural teeth, it is questionable whether alveolar mucosa provides adequate soft tissue adjacent to implants or whether keratinized epithelium is necessary. A 5-year longitudinal study by Schoo and van der Veldon[136] indicated that alveolar mucosa around teeth is not more likely to develop recession or inflammation than attached gingival. Similar observations were made by Krekeler et al[137] concerning soft tissue around implants. Clinical observations suggest that the presence or absence of attached gingiva around implants does not appear to affect long-term soft tissue health, bone loss, or implant survival rates. However, when alveolar mucosa directly surrounds the abutments, chronic trauma as a result of muscle influence in severely resorbed jaws can cause marginal irritation.[138] Han et al,[139] in a case report describing a surgical technique, indicated that replacement of unattached, nonkeratinized mucosa with keratinized gingiva provided attached gingiva around implants that was healthier and more resistant to inflammation. Azzi et al[140] indicated that an adequate zone of attached gingiva is necessary around anterior restorations to conceal the junction between an implant and a restoration. A comparative study by Wennstrom et al,[141] focusing on implants placed in keratinized tissues, nonkeratinized tissues, and mobile soft tissues, indicated that the lack of attached masticatory mucosa around an implant did not jeopardize the maintenance of healthy soft tissues.

Infection

Bacterial infection, mostly caused by gram-negative anaerobic rods and spirochetes, can cause peri-implantitis with apically progressive bone loss, resulting in loss of dental implants.[142] While implant failure has not been related to the presence of any specific bacterial microorganism, the same bacteria that are associated with periodontal disease are present more frequently around failing implants.[142,143] However, the presence of periodontopathic bacteria around implants is not in itself an indication of peri-implantitis.[144] Genetic and environmental factors determine the severity of the host reaction.

The microbial population around implants is influenced by the microbial population in the oral cavity. Mombelli et al,[145] in a study of implant patients with a history of periodontal disease, found that the microflora present intraorally before implant placement determined the composition of the microflora found around the subsequently placed implants. Thus, clinicians would be prudent to ensure that patients have the most optimal periodontal health possible before implant placement. In completely edentulous patients, the microflora adjacent to implants is similar in type to that from the adjacent mucosa, which is by nature not particularly periodontopathic.[146] In partially edentulous patients, the microflora present adjacent to implants tends to be the same as that adjacent to the natural dentition.[145,147] Thus, the natural teeth, if they are supporting colonies of pathogenic organisms, can become reservoirs to initiate bacterial infection around implants.[146,148-150] As expected, the microbial pathogens associated with periodontitis occur more commonly around implants exhibiting gingival inflammation.[151] Thus, preventive periodontal therapy should be maintained after implant placement to reduce periodontal pathogens throughout the oral cavity.

Quirynen et al,[152] in a study of 159 partially edentulous patients, showed that a larger number of pathogenic bacteria could be found around implants when teeth were present in the same jaw as the implants, as compared with patients with teeth only in the antagonistic jaw. The authors also found that probing depths deeper than 4 mm around the teeth did not increase incidence of pathogenic bacteria around implants, but if pathogenic bacteria were present around teeth, there was a corresponding presence around implants. They also showed that the same probing depths (4 mm or greater) that support pathogens around teeth were needed around implants to support significant numbers of the same pathogens. It seems reasonable that surgeons should try to reduce final probing depths around implants by using short abutments,[152] thinning the mucoperiosteal flaps, and using a surgical pack during abutment placement.[119]

Lee et al,[153] in a study of bacteria around implants and teeth, found microbial composition differences in patients with a history of periodontal or peri-implant disease, even when no active disease was present. These patients seemed to have an increased susceptibility to growth of those organisms. The etiologic role of specific microorganisms in implant failure is still not known; thus, patients with pathogenic bacteria are not necessarily poor candidates for implants. Mengel et al,[154] in a small study of implants in patients with histories of generalized chronic periodontitis and generalized aggressive periodontitis, showed success with implants in these patients 5 years after placement.

Contrary to what might be expected, Lindquist et al[155] showed that a patient's plaque control around implants was not a significant factor affecting bone loss, unless the patient smoked. However, the authors only studied mandibular implants. They also found that the more a patient smoked, the larger the amount of measurable bone loss, but even with the increased bone loss, no smokers lost implants in the 10-year length of the study.

Nonvital teeth and endodontically treated teeth may also potentially harbor bacteria that could affect implant health. There are case reports in the literature describing cross-infection from lesions of endodontic origin to implants,[156,157] with some leading to loss of implants. Of particular concern are descriptions of cross-infection from teeth with endodontic treatments that were long-standing, asymptomatic, and supposedly radiographically healed. [158] Apparently, microorganisms are persistent in the periapical area, even though treatment is judged successful by all measures generally used to assess endodontic treatments. As there is no current method to test the sterility of an apex of an endodontically treated tooth, caution in placing implants adjacent to such teeth is advisable. This is especially true if an implant adjacent to an endodontically treated tooth fails and the implant is to be replaced. Thus, if an endodontically treated tooth is adjacent to an implant placement site and there is any doubt as to the sterility of the apical area, it would be prudent to endodontically retreat the tooth or even extract it.

The surface characteristics of an implant can influence the amount of bacterial colonization. A rougher surface can potentially provide a better matrix upon which bacteria can grow and can afford more protection from saliva and natural muscle movement cleansing.[159] The smoother an implant surface, the less the ability of bacteria to adhere. The use of mechanical scalers (plastic), bacteriocidal chemicals (chlorhexidine or iodine), and YAG lasers[160] has been suggested as an appropriate counteractive measure.

Occlusal factors

Natural teeth are supported by periodontal ligaments with receptors that help protect teeth and the periodontium from excessive occlusal forces that can cause trauma to the supporting bone.[161,162] These neuromuscular reflexes are absent in osseointegrated implants. Clinically, a poorly developed occlusion on implant-supported restorations could have a deleterious effect on the supporting bone as well as on the accompanying prosthesis components.[163] Lindquist et al,[164] in a study evaluating the effects of occlusal forces on osseointegrated implants, indicated that occlusal overloading was the primary reason for bone loss around implants. Lundgren and Laurell,[165] in describing occlusal forces on prosthodontically replaced dentitions, suggest the need to minimize horizontal forces caused by premature contacts or steep cusps. However, several authors have demonstrated that the magnitude or direction of occlusal forces does not appear to have an effect on the stability of supporting implants and bone. Studies employing high implant overload have shown no effect on osseous integration success in animal models.[166-169] However, Isidor,[170] in an animal study, demonstrated bone loss surrounding implants subjected to extremely high off-axis loading forces. With these conflicting results, the effect of occlusal loading on bone supporting implants requires further research.

There may be more influence from occlusal forces on implants. Anecdotally, many clinicians have experienced the perceived consequences of the overloading of implants resulting in the loosening and fracture of components.[171-174] Occlusion can contribute significantly to the maintenance of implant screws.[175] Lateral excursive contacts act as separating forces for the implant/abutment/restoration screw connection and should be avoided if possible, or at least minimized. It has been suggested that off-axis centric occlusion contacts are the most commonly overlooked causes of forces leading to the separation of implant screws. The location of these contacts should be modified, as necessary, to provide forces along the long axis of the implant.[175] Thus, the occlusal scheme for an implant-supported restoration should be designed to decrease cuspal interferences, centralize forces along the long axis, and minimize lateral forces; in other words it should be like that of a similar restoration supported by a natural dentition.[118]

LOCAL MEASURES TO IMPROVE OUTCOMES

In summary, the most effective local measures to increase implant success are to follow the guidelines previously described as to the minimum quantity and quality of bone necessary to support osseous integration and subsequent restoration. Also, as with all dental treatment, optimal oral hygiene should be maintained, both around implants and teeth, reducing potential reservoirs of periopathogenic bacteria to maximize the potential for successful treatments. Because individual response to potentially destructive bacteria is an important variable, screening for the presence of particular periodontopathic bacteria should not be used to exclude patients from implant treatment, nor should antibiotics be used universally to remove these bacteria. Research is needed to provide methods of identifying individuals at risk, so that antibacterial therapy can be used sparingly and appropriately.

The use of presurgical chlorhexidine gluconate 0.12% oral rinses (Peridex; Proctor & Gamble, Cincinnati, Ohio) has been suggested by Lambert et al[176] as a means to reduce infectious complications around implants. In a study of almost 600 patients receiving over 2600 implants, the authors reported that chlorhexidine rinses immediately before implant placement surgery and second-stage surgery, and twice daily for 2 weeks after the surgery, reduced the incidence of postsurgical infection by half and cut early losses of implants sixfold. Young et al[177] reported that such rinses also reduce the bacterial contamination of collected bone debris to be used for augmentation procedures. As a more complete guide, in 2001 Quirynen et al[178] published a comprehensive literature review discussing infectious risks for implants and methods to reduce the chances of infection.

PROSTHESIS DESIGN FACTORS

Number and size of implants

Theoretically, the greater the number and the larger the size of implants placed, the larger the surface area for osseous integration and the better the chance of having stable implants for restoration. The major limiting factor in this regard is the anatomy of the patient. Anatomical considerations such as the inferior alveolar canal or maxillary sinus, and local factors such as ridge height and width, may limit the placement of an ideal number or length of implants.

Regarding implant length, 7 mm has been recommended as a minimum requirement.[141] Winkler et al,[179] in a study of almost 300 implants, compared the survival rates of "3+"-diameter (3 mm to 3.9 mm) and "4+"-diameter (4 mm to 4.9 mm) implants with lengths of 7, 8, 10, 13, and 16 mm. Results after 36 months indicated that shorter implants had statistically lower survival rates compared to longer implants. With regard to width, the implants "3+" mm in diameter had a lower survival rate than the "4+" group. In addition, the shorter the implant, the greater the number of implants that should be placed for a completely implant-supported prosthesis.[118] Recent observations by Worthington and Rubenstein[180] have indicated that less bone height may suffice when a definitive overdenture prosthesis rather than a fixed implant-supported prosthesis is planned.

Spacing of implants

There must be adequate space between implants, and between natural teeth and implants, for proper integration and tissue health. In general, there should be 3 mm between implants and between teeth and implants.[118] Thus, the space needed for 2 implants of 4 mm diameter to be placed between natural teeth is 17 mm. Generally, the anterior mandible has adequate bone for placement of 4 to 6 implants.[117]

Cantilevers

Historically, implant-supported prostheses were designed for completely edentulous patients and particularly for edentulous mandibles.[163] Initial treatments involved the placement of 4 to 6 titanium implants in the mandible between the mental foramina with bilateral distal cantilevers. Generally, these cantilevered sections were limited to an arbitrary 20 mm in length on each side.[118] A more recent analysis by McAlarney and Stavropoulos,[181] studying the number of implants, materials, and the anterior-posterior spread of the implants, has suggested that the cantilever length desired clinically will be less than that calculated from theoretical equations. The authors studied 55 patients and determined that, if the anterior-posterior spread of the abutments is greater than 11.1 mm, then the length of a cantilever needed for adequate occlusion can generally be supported. If a significant anterior-posterior spread of the implant placements cannot be achieved, an overdenture or bar-clip–type denture should be considered, rather than a long cantilever fixed implant-supported prosthesis.

Although the cantilever type of prosthesis has been an effective solution for the restoration of an edentulous mandible, it has been a much less predictable solution for the edentulous maxilla.[163] The nasal cavity and maxillary sinuses often interfere with implant site selection, especially in patients with severe bone resorption.[182] Adequate bone for implants may be limited to the canine eminences, lateral wall of the nasal cavity, and medial wall of the sinuses.[117] Posteriorly, the maxilla presents further difficulties due to the resorption pattern, quality of bone, and proximity of the sinuses. Even with advanced surgical techniques such as immediate implant placement, ridge augmentations, and sinus lift procedures, and technically advanced implant designs, predictable outcomes of implant treatment in the posterior maxilla may be elusive. The long-term success of implants in the edentulous maxilla has been documented to be greater than 80%,[183-185] but some studies have indicated significantly lower success rates in the posterior edentulous maxilla compared to the anterior areas.[186,187] Even if osseous integration is a success, frequently cited complications of maxillary implant-retained restorations include inadequate lip support and esthetic problems, difficulties with speech, too much space beneath the prosthesis allowing air to escape in function, or too little space compromising access for oral hygiene procedures.[188-190]

As a result, the use of implant-retained overdentures has been suggested in the maxilla, rather than fixed or fixed-detachable implant-supported prostheses that can be successfully used with a similar configuration of missing teeth in the mandible.[191] However, research continues to elucidate techniques that provide more predictability for implant treatment in the maxilla. Angled implants placed in lieu of expensive, time-consuming, and somewhat unpredictable sinus lift or grafting procedures have been attempted.[192] Aparicio et al,[192] in a study of 25 patients, found that success with angled implants over an approximate 2- to 7-year period, was comparable to that with implants placed axially.

Cemented versus screw-retained restorations

The decision to use screw-retained or cemented definitive restorations is largely at the discretion of the practitioner. Taylor and Agar,[173] although recognizing retrievability as the major advantage of a screw-retained restoration, list 5 reasons for the use of cemented prostheses: screw openings will not interfere with esthetics or occlusion; a reduced number of components reduce the cost of cemented restorations; screw loosening is not a complication; the possibility of a more ''passive fit'' exists with a cemented restoration, since the potential strains induced in a screw-retained restoration would not be present; and the use of cemented restorations more closely follows conventional nonimplant restorations.

If screw-retained prostheses are the restoration of choice, the practitioner should understand the mechanics of the use of threaded screws. An overview of implant screw mechanics has been presented by McGlumphy et al.[175] The authors suggest several factors to minimize screw-loosening. Lines of occlusal forces should be along the long axis of the implants, cantilever lengths should be minimized, posterior working and nonworking contacts should be eliminated, centric occlusion contacts should be centralized along the long axis of the implant, anterior guidance should be shared with natural teeth, antirotational features of implants for single teeth should be engaged, components should be torqued to the manufacturer's specifications, and frameworks should fit passively. Actually, these criteria should apply to cemented restorations as well, since abutments are usually screwed to the implant body beneath the cemented restoration.

Occlusal materials

Traditionally, much of the rationale for selection of occlusal materials for implant restorations was based upon the original use of implant systems in the edentulous mandible. It was assumed that acrylic resin occlusal surfaces, as found in denture teeth, would provide some absorption of occlusal forces and not transmit them to bone.[119] Furthermore, theoretical models indicated that resin occlusal surfaces would prevent transmission of traumatic forces to bone and not damage the implant-bone phase boundary, thus reducing the risk of implant failure.[119,193] As implant-supported restorations began to be fabricated for partially-edentulous arches, demands for materials with improved physical and mechanical properties increased. Currently, metal and ceramic occlusal surfaces provide superior esthetics and wear resistance and are generally used with implant-supported restorations. In vitro studies have shown that resins reduce impact forces when compared with porcelain.[112,194] However, studies simulating functioning implants have not shown significant differences in force transmission via these materials when strain gauges were placed on implants in vivo[195] or in cadaver bone.[196]

Passivity of fit

In prosthodontics in general, much effort has been expended on techniques to ensure better fitting prostheses. There are well-known sequelae of restoration misfit such as recurrent caries and loosening of the restoration. Improvements in impression techniques, die materials, investing materials, and fabrication techniques have all been suggested to improve the fit of the tooth-restoration phase boundary. Authors have assumed that misfit of implant-supported restorations could transfer strain to the implant-bone phase boundary in sufficient amounts to cause ultimate implant failure.[197-199] However, studies designed to assess the effects of the degree of misfit of an implant-supported restoration on the implant-bone phase boundary have been unable to demonstrate a negative effect of misfit on this area.[200-203] From the literature, there seems to be no consensus as to the degree of misfit tolerable or the long-term effects on the implant. However, the incidence of screw loosening appears to increase if a nonpassive prosthesis framework is placed.[175] It would seem prudent, therefore, to fabricate restorations that fit the implants as passively as possible.

Implant-tooth relations

Prostheses supported by implants and natural teeth may offer a solution to the restoration of posterior edentulous areas in which only a single implant can be placed. The use of these combination-supported prostheses first appeared in the literature in the mid 1980's.[203-206] Authors have debated the efficacy of this design as well as whether a rigid or nonrigid connector between an abutment tooth and an implant is required.[207-209] Tooth intrusion has been a frequently observed consequence of these types of combination restorations.[210-212] Many theories have been forwarded to explain this, with no common agreement.[213] Currently, the consensus appears to be to avoid the combination-supported restoration in favor of restorations using a single-tooth implant or placement of additional implants to retain a fixed prosthesis.[213]

Implant surface material

In designing the implant-supported restoration, attention must be given to the interaction of the various implant component materials with each other and the oral environment. Restorations or prostheses with different alloy compositions may develop galvanic (coupled) corrosion problems when in contact.[117,214,215] An in vitro investigation by Thompson et al[216] demonstrated the susceptibility of implant components to galvanic-type corrosion. Lemons[217] studied restoration failures as a result of galvanic corrosion properties of coupled restorative and implant materials. It is possible that if an implant receives a cast restoration that makes contact with an amalgam restoration on an adjacent tooth, there could be coupling between the amalgam and titanium or titanium alloy implant. However, implants coupled with noble alloys of gold, palladium, and silver show little susceptibility to corrosion.[216,218] Given the numbers of implant-supported restorations and the relative paucity of reports of untoward events concerning corrosion, this may not be of current clinical significance.

The different implant systems available present several types of surface treatments with the goal of maximizing bone-implant contact. Some of the available treatments are machining, etching, airborne-particle abrasion with soluble particles, titanium plasma spraying (TPS), and hydroxyapatite (HA) coating. Studies designed to examine the relative merits of these treatments have produced mixed results. A study by London et al[219] evaluated the bone contact percentage with several different surface coatings on implants. The authors found that HA coatings offered no advantage as compared to titanium and that rough HA-coated surfaces scored similar to rough TPS surfaces in terms of a bone-contact percentage. A "dual etched" titanium surface had the highest percentage of bone contact in this study. However, Novaes et al, [220] in an animal study, found that any of the studied treatments that added roughness to the implant surface (HA-coating, TPS, airborne-particle abrasion) showed bone contact percentages higher than that of a machined titanium surface. Whether this is a significant factor to long-term implant success remains to be established.

DESIGN FEATURES TO IMPROVE OUTCOMES

To minimize potential problems during the restorative phase, it is imperative that the dentist restoring the implants, after consultation with appropriate specialists, be primarily responsible for the treatment planning. This is a challenging responsibility, especially in light of the lack of rigorous scientific principles to guide a practitioner with prosthesis design and the catastrophic nature of implant failure.

Thus, as with any prosthodontic restoration, meticulous attention must be given to treatment planning. Subsequent to the customary medical and dental history analysis, intraoral and extraoral examination, and radiographic analysis, diagnostic casts should be made. These casts, along with a facebow transfer and occlusal registration, are essential for treatment planning and restoration design. Also, properly oriented diagnostic casts are needed to evaluate the remaining dentition, residual bone, and maxillomandibular relationships.[101,125]

FUTURE RESEARCH

In the past, principles and concepts, often empirical in nature, for the treatment of natural teeth have been extrapolated to apply to treatment with dental implants. In the current "evidence-based" environment, this is no longer acceptable. Further research is needed to provide better answers to the "how" and "why" of successful implant-supported restorations. New cellular and subcellular techniques may help develop methods to increase the rate of osseous integration, reduce the healing time, and provide compelling evidence for the immediate loading of implants at the time of placement. More study is needed on the role of antibiotics during implant therapy. More knowledge about host immunity factors could provide invaluable predictors of treatment success. As smoking is identified as one of the major controllable factors for implant failure, more definitive smoking cessation protocols regarding length of time of cessation would be helpful. The appropriate amount of time to wait after an infection in an implant site before implant placement has to be determined. Longer-term research is needed to follow different treatment techniques in different patient situations, specifically to identify the so-called "cluster phenomena" factors. Improved methods to assess local bone quality prior to actual surgery are necessary. More reliable methods of augmenting bone need to be identified. The effects of design variables, such as occlusal load bearing and differences in surface coatings, require quantification and documentation in long-term studies. It is hoped that research into new fabrication and surgical techniques will reduce the costs of implant-supported prostheses and make this treatment option more widely available.

This article has not discussed the issue of esthetic restoration with implants. Because of the inherent objectiveness of evaluating esthetics, there is a lack of quantifiable evidence-supported guidelines regarding esthetics. Future research could aim to quantify the area of esthetics so that such guidelines could be established.

Finally, clinicians need the results of randomized, controlled clinical trials for evidence-based decision-making. However, these types of studies are difficult to design and are time-consuming and expensive. Furthermore, with the rapid deployment of commercial implant products, an implant may be obsolete by the time a rigorous study is completed. However, after more than 20 years of implant therapy, basic science research should be able to provide information on which products should be selected for meaningful clinical trials. Until this can be done, the design of implant restorations will be based on less evidence than is desirable.

SUMMARY

Treatment planning for the placement and restoration of osseointegrated dental implants involves the consideration of many variables, including systemic and local host factors and the design of the prosthesis. This literature review provides a summary of evidence-based principles to guide the dentist in making planning decisions. Limitations in current knowledge of this topic and directions for future research were also suggested.

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