Endosseous Integration

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Abstract

Osseointegration, is defined as a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant, is critical for implant stability, and is considered a prerequisite for implant loading and long-term clinical success of end osseous dental implants. Successful clinical employment of endosseous implants requires anchorage in bone to withstand functional loading. This idea is by no means novel, since both archaeologic and histologic records provide clear evidence of dental endosseous integration. Indeed, the increasing employment of dental implants led to the coining of the term of "osseointegration" in 1969.

Keywords: Endosseous Integration; Implants; Contact Osteogenesis

Introduction

Osseointegration, is defined as a direct structural and functional connection between ordered, living bone and the surface of a load-carrying implant, is critical for implant stability, and is considered a prerequisite for implant loading and long-term clinical success of end osseous dental implants [1].

Successful clinical employment of endosseous implants requires anchorage in bone to withstand functional loading. This idea is by no means novel, since both archaeologic and histologic records provide clear evidence of dental endosseous integration [2]. Indeed, the increasing employment of dental implants led to the coining of the term of "osseointegration" in 1969. While this term has found considerable use in the clinical community as a means of describing the functional stability of an endosseous implant [3]. The mechanisms by which endosseous implants become integrated in bone can be subdivided into three separate phenomena, each of which can be tested experimentally [2].

Distance and Contact Osteogenesis

The terms distance and contact osteogenesis were first described by Osborn and Newesley in 1980 and refer to the general relationship between forming bone and the surface of an implanted material [3].

While their classification was linked to different implant material types, rather than the biologic mechanisms underlying their histologic observations, it still provides one of the most useful starting points in understanding the mechanisms of endosseous integration. Their terms describe essentially two distinctly different phenomena by which bone can become juxtaposed to an implant surface, and these are illustrated in Figure 1.
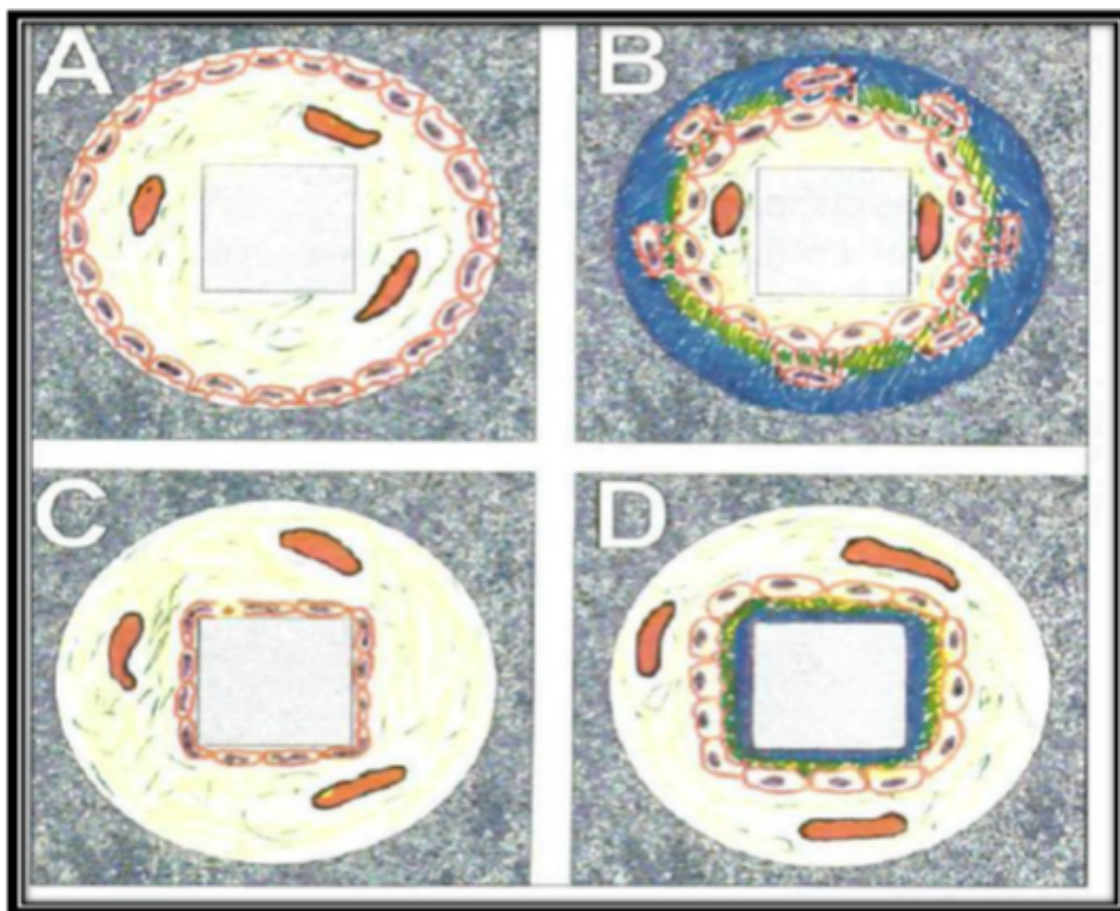
Figure 1: *Line drawings to illustrate distance (A and B) and contact (C and D) osteogenesis. A. osteogenic ceils line the old bone surface, while in C, osteogenic cells have first been recruited to the implant surface. The blood supply of these cells is between the cells and the implant in A, but between the cells and the old bone in C. In terms of bone matrix elaboration, A results in B, in which bone is laid down on the old bone surface. This is in sharp contrast to D, where new (de novo) bone is laid down on the implant surface, in each case (A + B; C + D), the secretory bone ceils recede towards their blood supply. (Note: the old bone-implant gap is exaggerated for graphic convenience).*

In the first, distance osteogenesis, new bone is formed on the surfaces of bone in the peri-implant site. Similar to normal apposition [bone growth, the existent bone surfaces provide a population of osteogenic cells that lay down new matrix, which, as osteogenesis continues, encroaches on the implant itself. Thus, an essential observation here is that new bone is not forming on the implant itself, but rather that the implant becomes surrounded by bone. One can predict, in such a case, that it would be impossible to achieve the phenomenon of bone – bonding [2].
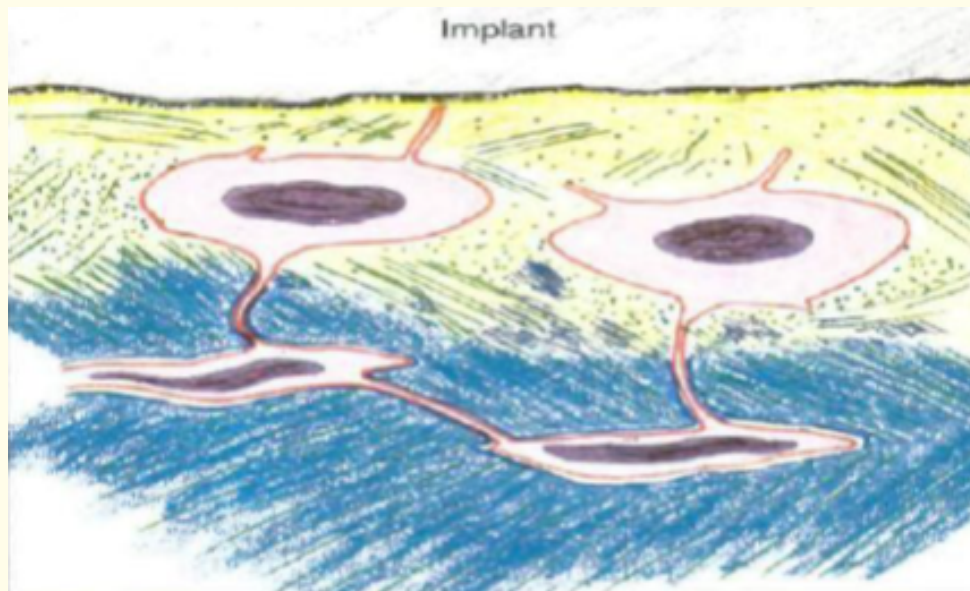
Figure 2: *The result of distance osteogenesis is shown diagrammatically. Bone matrix (blue) is being laid down away from the implant surface by cells which, as a result, are pushed closer and closer to the implant surface. These cells, which have the ability to change shape in the essentially fluid extracellular compartment, can extend cell processes towards the implant surface. However, the matrix has approached so closely to the latter that the source of blood supply for these metabolically active cells has been lost, and thus their survival will be compromised. See also the discussions of cell/implant contacts in steflik., et al [12].*

A recent paper by Steflik., *et a*l. exemplifies this. In a series of transmission electron micrographs, they described the growth of bone toward the implant surface as classically described in 1983 by Albrektsson [4].

In the second phenomenon, contact osteogenesis, new bone forms first on be implant surface. Since, a priori, no bone was present on the surface of the implant upon implantation, the implant sur- "face must become colonized by a population of osteogenic cells before initiation of bone matrix formation. This occurs, too, at remodeling sites where an old bone surface is populated with osteogenic cells before new bone can be laid down [2].

The common factor in these cases is that we are expecting bone to form for the first time at these sites. We have employed the term *de novo* hone formation to describe such an event and to distinguish this phenomenon from appositional growth of bone, where the continuum of bone formation represents the transient anabolic behavior of already differentiated osteoblasts. Clearly, then, an essential prerequisite of *de novo* bone formation is the recruitment of potentially osteogenic cells to be site of future matrix formation. We use the term differentiating osteogenic cells to define this population, and describe their migration separately as osteoconduction. The result of such cell migration is illustrated in Figure 1C, where the implant surface is first populated by differentiating osteogenic cells that start to secrete matrix (see below, "*De Novo* Bone Formation") on the implant surface.

While both distance and contact osteogenesis will result in the juxtaposition of bone to the implant sur-face, the biologic significance of these different healing reactions is of considerable importance in both attempting to unravel the role of implant design in endosseous

integration, and in elucidating the differences in structure and composition of the bone-implant interface. In reality, one can reasonably assume that any endosseous healing compartment will display both distance and contact osteogenesis phenornena [2].

Nevertheless, when considering contact osteogenesis, one can, both phenomenologically and experimentally, separate this bony healing response into the Kvo distinct early phases of osteogenic cell migration (osteoconduction) and *de novo* bone formation. Subsequently, a third tissue response that of bone remodeling, will also, at discrete sites, create *de novo* bone formation at an implant surface [2].

Osteoconduction

As discussed above, contact osteogenesis relies on the migration of differentiating osteogenic cells to the implant surface. Typically, differentiating osteogenic cells are derived, at bone remodeling sites, from undifferentiated peri-vascular connective tissue cells. A more complex environment characterizes the peri-implant healing site since this will be occupied, transiently, by blood. In this case, as in fracture healing, migration of the connective tissue cells will occur through the fibrin that forms during clot resolution. This connective tissue stromal cell population will provide both the early connective tissue that replaces the fibrin and a source of osteogenic cells. It is important to stress that once differentiating osteogenic cells start secreting bone matrix, they stop migrating.

Thus, bone ingrowth into three-dimensionally complex surfaces, such as porous coated implants or the macroporous bone-fillers illustrated by Osborn and Newesley will be the result of osteogenic cell migration [3].

De Novo Bone Formation

This *de novo* bone formation cascade is a four-stage process differentiating osteogenic cells initially secrete a collagen-free organic matrix that provides nucleation sites for calcium phosphate mineralization [2].
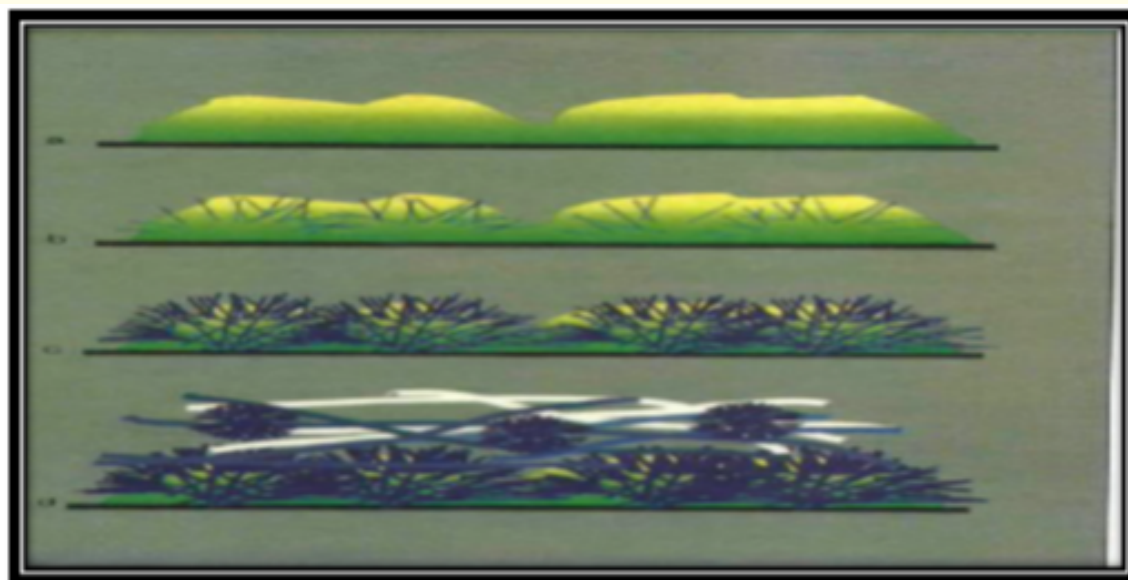

Figure 3: *De novo bone formation.*

The four-stage sequence of events of *de novo* bone formation at a solid surface. This series of drawings is equally applicable when the solid surface is an implant or old bone at a remodeling site. An extensive description of this sequence can be found in Davies., *et al.* "(a) Secretion of the two noncollagenous proteins, osteopontin and bone sialoprotein. (b) Calcium phosphate nucleation at the calcium binding sites of one, or both, of these proteins, (c) Crystal growth phase, (d) Collagen production and subsequent collagen mineralization. By this cascade of events, the collagen compartment of the elaborated bone matrix is separated from the underlying solid surface by a cement line of about 0.5m thickness.

We have identified two noncollagenous bone proteins, osteopontin and bone sialoprotein, in this initial organic phase, but no collagen. Importantly, in the implant context, it should be emphasized that the substratum does not act as an epitactic nucleator in this biologic mineralization phenomenon. Calcium phosphate crystal growth follows nucleation, and concomitant with crystal growth at the developing interface, there will be initiation of collagen fiber assembly. Finally, calcification of the collagen compartment will occur, both in association with individual collagen fibers or in the interfiber compartment. Thus, in this process of *de novo* bone formation, the collagen compartment of bone will be separated from the underlying substratum by a collagen- free calcified tissue layer containing noncollagenous bone proteins. This layer is approximately 0.5-pm thick, as are cement lines that form the interface between old and new bone at reversal sites [5].

Bone Bonding

The pioneering work of Hench (reviewed in Hench and Wilson), two classes of endosseous implants have been identified: bone-bonding and nonbonding. While metals such as titanium are nonbonding, calcium phosphate materials are considered bone-bonding. The mechanism for the bone-bonding phenomenon is generally accepted to be a chemical interaction that results in collagen from the bony compartment interdigitating with the chemically active surface of the implant [2].

Bone Remodeling

Bone remodeling is of particularly critical importance in the long-term stability of the transcortical portion of an endosseous implant, since cortical bone will necrose as a result of the surgical trauma to the tissue. This has been demonstrated by Roberts^^ to extend up to 1 mm away from the implant surface and addressed experimentally by Brunski and by Hoshaw we will not treat this phenomenon in any detail since it has been addressed thoroughly by the latter authors. However, two important points should be made. First, during this long-term phase of peri-implant healing, is only through those remodeling osteons that actually impinge on the implant surface that *de novo* bone formation will occur at these specific sites on the transcortical implant." The remainder of the transcortical portion of the implant will be occupied by old, dead bone or connective tissue space created by preimplant necrosis and lysis of bone tissue. Second, although trabecular remodeling also occurs, this is not vital to implant stability [6].

The Branemark novum concept [7]

The Novum Concept was conceived in 1980. Branemark Novum, an essentially new treatment modality is based on with the Branemark Classic osseointegration procedure, a two-step surgical approach with varying time intervals between the steps. The distinctive feature of Novum is that it requires only 6 to 8 hours for the entire reconstruction and thus gives the patient a third dentition in just 1 day.

Novum system is a one-day treatment of the edentulous or periodontally hopeless mandibular dentition. There are four drill templates and eight drill guides that precisely position three implants which are totally parallel and level. A prefabricated lower bar is placed on the three implants, and an upper bar fits on the lower bar. The restorative dentist has previously selected denture teeth and recorded the vertical dimension of occlusion. The case is waxed up, adjusted, processed and fit and insertion done on the same day.

The advantage of this procedure is completion of the surgery and reconstruction in one day, with rigid stabilization at the time of implant placement and also the reduced cost. Disadvantages include appearance of the lower bar when the patient pulls down his or her

lower lip, surgical procedure is very labour-intensive a much more demanding than routine implant surgery, limited patient selection due to anatomic limitations and also the surgical template might not fit all mandibles.

Early loading

Early loading refers to an implant supported restoration that is in occlusion between 2 weeks and 3 months after implant placement. A fundamental goal of early loading is improving bone formation in order to support occlusal loading at two months.

Delayed loading

It refers to implant prosthesis with an occlusal load after more than 3 months after implant placement. The delayed occlusal loading approach may use either a two-stage surgical procedure that covers the implants with soft tissue or a one-stage approach that exposes a portion of the implant at the initial surgery [8].

The rationale behind this approach is that premature loading of implants would lead to implant micro movement, caused by functional force, around the bone-implant interface during wound healing and may induce fibrous tissue formation rather than bone contact, leading to clinical failure. In addition, coverage of an implant has also been thought to prevent infection and epithelial down growth. Initial exposure or biomechanical stimuli often induced a fibrous connective tissue interface between implants and bone. Hence the submerged implants were preferable for initial rigid fixation [8].

Progressive loading

Branemark first proposed the concept of progressive or gradual bone loading during prosthetic reconstruction to decrease crestal bone loss and early implant failure of endosteal implants in 1980 [9].

Factors affecting Progressive loading of implants:

1. Bone Density
2. Bone-Implant Interface

A review of the literature of *in vivo* and *in vitro* studies has shown that dynamic or cyclic loading is necessary to cause a significant metabolic change in the bone cell population. The greater the rate of change of applied strain in bone, the more bone formation is increased. The effect of applied strains on bone is dictated not only by the rate of the applied load but also by the magnitude and duration. Cyclic loading is necessary to cause a significant metabolic change in bone cell population. Lower-magnitude loads applied for many cycles can cause the same anabolic effects of larger loads applied for a limited number of cycles. Therefore, a range of clinical conditions may equate to an increase in bone density. The bone strength is related directly to density, with Division Dl bone being 10 times stronger than D4 bone to stresses that cause microfracture. Therefore, increasing bone density around an implant increases the strength of bone, which in turn can help avoid crestal bone loss and implant failure [10].
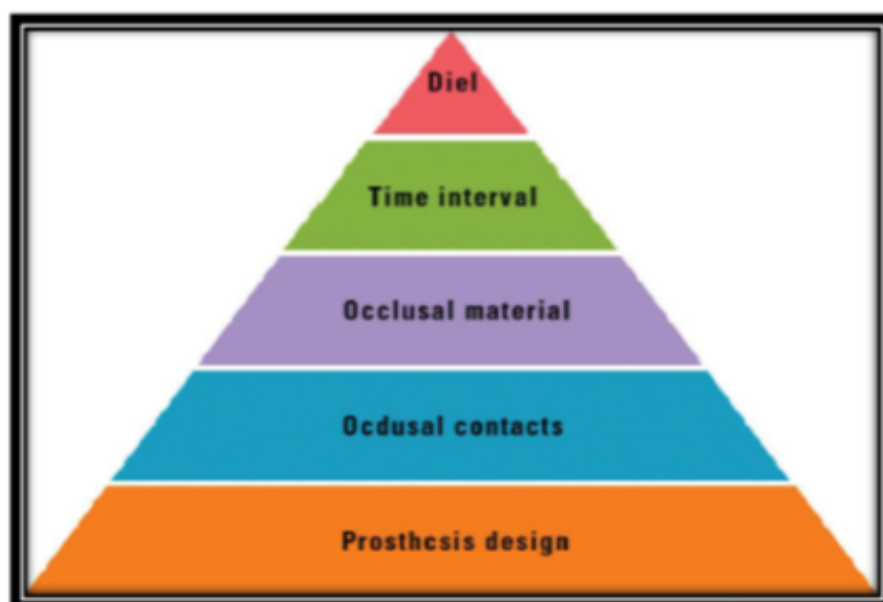
Elements of progressive loading protocol

Figure 4

Certain studies have also evaluated the effect of loading on the success of dental implants. Henry and Rosenberg 129 used Branemark implants with bicortical anchorage. After a time period of 6 - 7 weeks before loading the implants, a success rate of 100% was obtained whereas Salama., *et al.* found no difference in success rate between the randomly applied immediate and delayed loading [9].

Scortecci also studied the immediate loading of implants with bicortical anchorage. They demonstrated that bicortical anchorage and the placement of a rigid prosthesis allows the immediate loading of implants, with a predictable outcome [10].

Horiuchi., *et al.* also studied the immediate loading of Branemark implants and suggested it was as predictable as delayed loading in the placement of overdentures, both in the maxilla and mandible.

Jo., *et al.* concluded that the main factor influencing the success of immediate loading is the primary stability of the implants at the time of the loading [12].

Vercruyssen and Quirynen showed in their long-term study, that some factors such as smoking, guided bone regeneration, the presence of dehiscence and bone quantity clearly showed a significant impact on the marginal bone loss around the dental implants [11].

With the trend of shortening treatment time and reducing patient discomfort, immediate loading implants has emerged. However, meticulous selection is needed to integrate this treatment into daily practice. Regular maintenance may be another factor to ensure the long-term success of immediately loaded implants. In addition, factors that may influence the outcome of this approach such as surgery related, host factors, implant and occlusion-related factors should be considered and analyzed prior to initiation of treatment.

Loading concepts	Indications	Contraindications	Advantages	Disadvantages
Immediate loading	• Adequate bone quality • Sufficient bone height and width • Ability to achieve and adequate anteroposterior spread between the implants	• Poor systemic health • Severe parafunctional habits • Bone of poor quality • Compromised bone height and width	• Eliminates the need for and maintenance of removable provisional prosthesis • Improves bone healing • Reduced treatment time and cost effective	• Cannot be applied to every implant patient • Requires more chair side time
Early loading	• Inability to achieve an adequate AP spread • Sufficient bone quality	• Smokers with uncontrolled DM • History of failed implants • Large deviation in saggital/ vertical bite relation	• Reduced treatment time • Cost effective	• Crestal bone loss • Primary stability compromised
Delayed loading	• Can be done for all prosthesis	• No absolute contraindication	• Reduced risk of bacterial infection • Prevents apical migration of oral epithelium along implant body	• Time consuming
Progressive loading	• Few implants planned • Softer bone types	• No absolute contraindication but most critical in D4 type bone • No early implant failure	• Decreased crestal bone loss	• Time consuming

In the studies reviewed, the outcomes tend to be more favorable for implants that are loaded after a period of Osseo integration, although the difference in success rates between the immediate and delayed loading of implants do not reach statistical significance.

The only parameter that appears to influence the success of immediate loading is the quality of the bone, which it is recommended should be type II. Neither the length, the localization nor the antagonist of the implant has any significant influence [7].

Success Criteria for Implants

NIH proposal – Schnitman and Shulman, 1979	Proposal by Albrektsson, Zarb, Worthington and Eriksson, 1986
1. Mobility of less than 1mm in any direction	1. That an individual, unattached implant is immobile when tested clinically
2. Radiologically observed radiolucency graded but no success criterion defined	2. That a radiograph does not demonstrate any evidence of peri-implant radiolucency
3. Bone loss no greater than a third of the vertical height of the implant	3. That vertical bone loss be less than 0.2 mm annually following the implant's first year of service
4. Gingival inflammation amenable to treatment. Absence of symptoms and infection, absence of damage to adjacent teeth, absence of paresthesia and anaesthesia or violation of the mandibular canal, maxillary sinus or floor of the nasal passage.	4. That individual implant performance be characterized by an absence of persistent and/or irreversible signs and symptoms such as pain, infections, neuropathies, paresthesia, or violation of the mandibular canal.
5. To be considered successful, the dental implant should provide functional service for five years in 75% of the cases.	5. That, in the context of the above, a successful rate of 85% at the end of a five-year observation period and 80% at the end of a ten-year period be a minimum criterion for success.

Criteria for implant success

The criteria proposed herein are relatively easy to apply, and above all ensure a degree of clinical success that is comparable with that experienced in conventional prosthodontic therapy.

Factors Responsible for Failure of Osseointegration in Oral Implants [14]

Implant complications and failures

A multifactorial background for implant complications and failure has been extensively reviewed by Esposito and co-workers. Factors affecting early failure of dental implants may be broadly classified as: implant-, patient- and surgical technique/environment-related. Three major etiologic factors have been suggested:

Infection: Bacterial infection that leads to implant failures can occur at any time during implant treatment.

Several terms are currently used indicating failing implants or complications. These are: peri-implant disease, peri-implant mucositis, and peri-implantitis. Peri-implant disease is a collective term for inflammatory reactions in the soft tissues surrounding implants. Peri-implant mucositis is a term describing reversible inflammatory reactions in the soft tissue surrounding implants.

Other soft tissue complications seem mainly to have an infectious etiology. Fistulations and hyperplastic mucositis are often found in relation to loose prosthetic components. Abscesses can occasionally be seen in relation to food particles trapped in the peri-implant crevice.

Impaired Healing: It is believed that the magnitude of the surgical trauma (lack of irrigation and overheating), micromotion and some local and systemic characteristics of the host play a major role in implant failures related to impair healing.

Early Loading: Implant failures related to overload include those situations in which the functional load applied to the implants exceeds the capacity of the bone to withstand it.

Failures that happen between abutment connection and delivery of the prosthesis, probably caused by unfavourable loading conditions or induced by the prosthetic procedure, considered to have an overload etiology. Other attributes to implant failures are poor surgical technique, poor bone quality and poor prosthesis design in addition to the traumatic loading conditions.

Esposito., *et al*. defined biological failures related to biological process, and mechanical failures related to fractures of components and prostheses. Koutsonikos added the categories of iatrogenic failure and failure due to patient adaptation. El Askary., *et al*. further defined failure as ailing, failing, or failed implants.

Patient factors

Patient factors are important determinants of implant failure. Ekfeldt., *et al*. identified the patient risk factors leading to multiple implant failures and concluded that a combination of several medical situations could provide a contraindication to implant treatment [15].

Hutton., *et al*. showed that subjects with one implant failure would be likely to have others, and Weyant stated that a positive medical history is associated with an increase in implant loss and also observed a 30% increase in the probability of removal of a second implant in patients with multiple implants presenting with one failure [16].

This evidence indicates that implant failures are not randomly distributed in the population, but seem to occur in a small subset of individuals.

Medical status

Diabetes

Diabetic patients experience delayed wound healing, which logically affects the osseointegration process. Uncontrolled diabetes has been shown to inhibit osseointegration and leads to implant failure. Fiorellini., *et al*. demonstrated a lower success rate of only 85% in diabetic patients, while Olson., *et al*. found that the duration of the diabetes had an effect on implant success: more failures occurred in patients who had diabetes for longer periods [15]. Fiorellini., *et al*. also observed that most failures in diabetic patients occurred in the first year after implant loading [14].

Cigarette smoking

The adverse effects of cigarette smoking on implant treatment are well documented. A longitudinal study by Lambert., *et al.* [16] found more failures in patients who smoked whereas Bain and Moy observed that a significantly greater percentage of failures implant occurred in smokers 11.3% than in non-smokers 4.8% [18].

The difference was highly significant for implants placed in all regions of the jaws, with the exception of the posterior mandible.

Cigarette smoking is associated with significantly higher levels of marginal bone loss, and the effect of smoking status on the hard and soft peri-implant tissues has been clearly shown [18]. The short-term benefits of a smoking cessation protocol suggested by Bain further explained the causal relationship between smoking and implant failure. The protocol specifies complete smoking cessation for 1 week before and 8 weeks after surgery. The results indicated that the smokers who complied with the cessation protocol displayed short-term implant failure rates similar to non- smokers, and significantly lower than smokers who did not follow the protocol [18].

Although the meta-analysis published by Bain., *et al*. concluded that patients who smoked fewer than 12 cigarettes per day did not significantly affect implant osseointegration, the adverse effects mentioned by the previous mentioned studies should not be ignored [18].

Age

Theoretically, patients with increased age will have more systemic health problems, but there is no scientific evidence correlating old age with implant failure. In young patients, implants such as 'ankylosed' devices can introduce problems in growing jaws. Op Heij reported that jaw growth can compromise oral implants and questioned the minimum age of a patient for implant treatment [17].

Iatrogenic factors

Overheating of bone during surgery

The most widely suspected explanation for failures occurring within 3 months of insertion is tissue overheating during the surgery. Salonen., *et al*. found that 5.8% of implants were lost due to failures of osseointegration. Bone necrosis can occur if bone is heated to a temperature of 47°C for 1 minute. The use of proper irrigation and sharp drills at low rotation can be employed to reduce heat generation [20].

It was recommended that increasing both the speed and the load of the hand piece would allow for more efficient cutting and less frictional heat.

Local factors

Peri-implantitis

Peri-implantitis is a chronic, progressive, marginal, and inflammatory reaction affecting the tissues surrounding osseointegrated implants that results in the loss of supporting bone. It accounts for 10% to 50% of all implant failures occurring after the first year of loading. The exact pathogenesis of peri-implantitis is still unclear. Plaque formation on natural teeth may play a role in the bacterial composition of the peri-implant sulcus. Elevated levels of gram-negative bacteria in the peri-implantitis sulcus of dentate patients. Lang., *et al*. in suggested a Cumulative Interceptive Supportive Therapy (CIST) protocol to treat developing peri-implantitis, which includes mechanical debridement, antiseptic treatment, antibiotic treatment, and regenerative or resective therapy [18].

Position of the implant site

Due to the poor quality of bone in the maxillae, the results of implant treatment anywhere in the maxillae are generally poorer than those in the mandible. Adell., *et al*. in found a failure rate of about 20% for maxillary implants. It found that 1 in 6, 17% implants placed in the maxillary molar area was lost as compared with 2 of 4, 54% placed in the mandibular molar region [19]. Jaffin and Berman reported the loss of 8.3% of 444 implants inserted in the maxillae in their 15- year experience. Generally, mandibular implants also survive longer than maxillary implants.

Bone quality and quantity

The most important local patient factor for successful implant treatment is the quality and quantity of bone available at the implant site. Patients with low quantity and low density of bone were at highest risk for implant loss.

Jaffin and Berman [21], in their 5-year analysis, reported that as many as 35% of all implant failures occurred in type IV bone due to its thin cortex, poor medullary strength, and low trabecular density. Unfortunately, the diagnosis of type IV bone is usually made during implant site preparation. Systemic osteoporosis has also been mentioned as a possible risk factor for osseointegration failure. Although the prevalence of osteoporosis increases among the elderly and after menopause, it appears that osteoporosis, as diagnosed at one particular site of the skeleton, is not necessarily seen at another distant site.

Irradiated bone

Implants can be used to provide anchorage for craniofacial prostheses. Radiotherapy in combination with surgical excision is the treatment generally employed for malignant tumors in that region, and osteoradionecrosis is one of the oral effects of radiation therapy. Although radiation therapy is not an absolute contraindication to implant treatment, the reported success rate is only about 70%. Long term studies are limited, showed increasing implant loss over time [19].

Conclusion

The ultimate success of implants is not only based on diagnosis, evaluation, treatment planning but also on having a knowledge regarding the complications of implants and their fruitful management. In short it is always better to remember: 'Prevention is better than cure' and 'a stitch in time saves nine.

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