ABSTRACT: This review focuses on five paradigms of implant dentistry which have undergone considerable modifications in recent years. An attempt was made to select and include all the relevant citations of the past 10 years. These five paradigms document the debate in the clinical and scientific community and include the aspects of (1) smooth vs. rough implant surfaces, (2) submerged vs. non-submerged implant installation techniques, (3) mixed tooth-implant vs. solely implant-supported reconstructions, (4) morsetaper abutment fixation vs. butt-joint interfaces, and (5) titanium abutments vs. esthetic abutments in clinical situations where esthetics is of primary concern.

Key words. Implant materials, surface roughness, installation techniques, implant suprastructures, abutment fixation.

Introduction

In the past two decades, replacement of missing teeth with implant- or tooth-implant-supported prostheses has become a widely accepted treatment for the oral rehabilitation of partially or fully edentulous patients. This revolutionary breakthrough is the result of research efforts conducted by two pioneers in implant dentistry, P-I. Brånemark (University of Gothenburg, Sweden) and A. Schroeder (University of Berne, Switzerland), who first put forth the concept of osseointegration or functional ankylosis, respectively (Brånemark et al., 1969, 1977; Schroeder et al., 1976, 1978, 1981). Both researchers described this biological phenomenon as “direct bone deposition upon the implant surface”. More recently, the existence of a direct biochemical bond without any space between the titanium surface and the bone has been investigated with the aid of transmission electron microscopy (Listgarten et al., 1992).

Since the development of clinically feasible treatment concepts and the manufacturing of optimal implant fixtures occurred independently of each other, it is not surprising that, in the research communities, differences of opinion exist for various implant systems. Also, different paradigms regarding the biological and technical aspects of implant systems have evolved. In the last 10 to 20 years, however, a widespread research effort involving physiologists, histopathologists, oral surgeons, materials scientists, periodontists, and prosthodontists has contributed to a better understanding of implant therapy. Hence, it was inevitable that at least some of the originally advocated rules and dogmas had to be re-evaluated. The aim of the present review is to identify some of the paradigm shifts in implant dentistry that have occurred within the last 5 to 10 years.

(1) Smooth vs. Rough Implant Surfaces

Implant surface texture has been recognized as one of 6 factors playing a central role in the process of osseointegration of oral implants (Albrektsson et al., 1981). Additional factors that are generally accepted as being of particular importance are: (1) biocompatibility, (2) design, (3) host tissue conditions, (4) surgical technique, and (5) loading conditions (Albrektsson et al., 1981). In the past two decades, implant surface modifications have attracted the attention of several research groups. Today, the 2 best-documented surfaces are the machined or turned titanium surface and the titanium plasma-sprayed (TPS) surface. TPS surface implants manufactured with a rough coating technique were introduced into implant dentistry more than 20 years ago (Schroeder et al., 1976, 1978, 1981). TPS coating creates a continuous rough surface and increases the surface area by approximately 6-10 times. This titanium plasma-sprayed layer is usually 20-30 μm thick, with a roughness of about 15 μm (Steinemann, 1996, 1998). The aim of the TPS coating was to accelerate bone apposition in the early healing phase by increasing the contact surface area between the implant and the bone, thereby improving implant anchorage. Over the past two decades, positive long-term results in fully and partially edentulous patients have been reported (Babbush et al., 1986; Buser et al., 1997, 1999a; Mericske-Stern et al., 1994). Recently, newly developed rough titanium surfaces have appeared on the market and are characterized by sand- or grit-blasting, TiO₂ blasting, acid etching, or combinations of the above, instead of the previously described coating technique (Buser et al., 1991; Gotfredsen et al., 1992). These surfaces, however, need to be evaluated carefully in long-term multicenter and
prospective clinical trials and should be critically compared with the clinically well-established and documented machined and/or TPS surfaces.

In the metaphyses of the tibia and femur of the miniature pig, implants with 6 different surface characteristics were directly and morphometrically compared, after 3 and 6 weeks of healing, with regard to bone-implant contact area (Buser et al., 1991). Electropolished and medium-grit-blasted implant surfaces showed the lowest percentage (mean, from 20 to 25%) of bone-to-implant contact area. Large-grit-sandblasted and TPS implant surfaces had a mean of 30 to 40% bone-to-implant contact area, while large-grit-sandblasted and acid-etched (SLA) (mean, from 50 to 60%) as well as HA-coated implant surfaces (mean, from 60 to 70%) showed the highest bone-to-implant contact area. The authors concluded that “the extent of bone-implant interface was positively correlated with an increasing roughness of the implant surface.” These studies have also been performed by means of removal torque biomechanics (Wilke et al., 1990). Also, the SLA and TPS surfaces yielded significantly higher removal torque values (RTV) than electropolished surfaces.

More recently, 4 different surface modifications of screw-shaped implants were evaluated histomorphometrically in rabbit bone after 12 weeks of healing (Wennerberg et al., 1998). The surface topography was measured with a confocal laser scanning profilometer. In general, blasted implant surfaces demonstrated more implant-to-bone contact when compared with machined or turned surfaces, indicating that the amount of bone in contact with the implant surface is dependent on the surface roughness.

Titanium surface roughness has also been shown in vitro to influence osteoblast proliferation and differentiation and to modulate the production of cytokines and growth factors (Martin et al., 1995; Boyan et al., 1996, 1998; Kiesewetter et al., 1996; Francois et al., 1997; Cooper et al., 1999), suggesting that titanium surface characteristics may influence several cell types and extracellular matrix components involved in tissue integration of endosseous oral implants. Based on numerous reports, there is increasing evidence that rough titanium surfaces provide a bone-to-implant anchorage superior to that provided by machined or turned titanium surfaces. This has been evaluated both by histomorphometric analysis of the bone-implant interface as well as by biomechanical studies assessing either pull-out, push-out, or removal torque values (RTV) (Thomas and Cook, 1985; Johansson and Albrektsson, 1987; Carlsson et al., 1988; Wilke et al., 1990; Buser et al., 1991, 1998b, 1999b; Gottfredsen et al., 1992, 1995; Ericsson et al., 1994b; Feighan et al., 1995; Wennerberg et al., 1995, 1996, 1997, 1998; Wong et al., 1995; Carr et al., 1997; Cochran et al., 1998). Collectively, these studies have clearly indicated that rougher implant surfaces have a greater bone-to-implant contact area and/or require higher forces to be removed from the bone than do implants with smoother surfaces (Fig. 1).

From a clinical point of view, rough titanium surfaces present several advantages with regard to treatment of partially and fully edentulous patients. These advantages include shorter healing periods for the SLA surface, the use of shorter implants, the reduction in numbers of implants, and the lack of necessity for bicortical implant anchorage. Results from clinical studies with the ITI® Dental Implant System (Buser et al., 1990, 1997) demonstrated that a three-month healing period is sufficient in both the mandible and the maxilla, provided that a bone quality of class I–III is present at the implant recipient site. Based on the promising results of several in vivo studies comparing SLA with TPS implant surfaces (Wilke et al., 1990; Buser et al., 1991, 1998b, 1999b; Cochran et al., 1998), a further reduction of the healing period appears feasible. However, no longitudinal clinical data are available as yet, and prospective multi-center clinical trials are still going on to test this hypothesis. The utilization of short 6- and 8-mm implants has attracted particular attention in clin-

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**Figure 1.** Removal torque values (RTV) in Newtonmeters (Nm) of three implant types machined (M), titanium-plasma-sprayed (TPS), and sandblasted with large-grit and acid-attacked (SLA) surfaces after 4, 8, and 12 wks of healing in the maxillae of miniature pigs (from Buser et al., 1999b; reprint ed with permission).
ical situations such as posterior mandibular and maxillary areas, where vertical bone dimensions are often limited. Furthermore, invasive surgical procedures such as sinus floor elevations or nerve transpositions may be avoided by the use of shorter implants. Results from a multicenter clinical study (ten Bruggenkate et al., 1998) that evaluated 6-mm short implants with a TPS-coated surface revealed a six-year cumulative success rate of 94%. Another multi-center long-term clinical study (Buser et al., 1997) reported a cumulative success rate of 91.4% at the eight-year follow-up for 8-mm TPS-coated short implants. A tripod-like implant installation has been recommended for screw-type implants with a turned surface to decrease bending moments and potential biomechanical complications, such as screw and abutment loosening (Rangert et al., 1997). On the other hand, the use of TPS-coated implants offers the possibility of replacing 3 missing teeth with a fixed partial denture (FPD) supported by 2 implants. This approach has been successfully applied with 10- or 12-mm ITI® implants over more than a ten-year period (Buser et al., 1997, 1998a, 1999a). Furthermore, this treatment modality significantly decreased the treatment-related costs when compared with the replacement of each missing tooth with an implant. In contrast to titanium implants with turned surfaces (Ivanoff et al., 1996), the installation of TPS-coated implants does not require bicortical anchorage (Buser et al., 1998a). Thus, shorter implants may be placed in the posterior or mandible and maxilla, thereby ensuring a safe distance to anatomical structures such as the canal of the inferior alveolar nerve or the sinus floor. This treatment concept presents minimal risks of damaging the neurovascular bundle of the mandibular canal and drastically reduces nerve complications during bicortical anchorage on the roof of the mandibular canal when machined screw-type implants are installed (Higuchi et al., 1995).

A third surface modification of titanium implants is characterized by calcium phosphate coating techniques, also called hydroxyapatite (HA) coatings (for review, see Jansen et al., 1999). As shown in several experimental studies (Thomas et al., 1987; Buser et al., 1991; Cook et al., 1992; Wong et al., 1995), HA-coated surfaces achieve a very intimate bone-to-implant contact and have been claimed to reduce the healing period (Block et al., 1987; Cook et al., 1987). Overall, clinical investigations have reported a high degree of success with hydroxyapatite-coated implants (Saadoun and LeGall, 1992; Block et al., 1996). However, some concerns about the biodegradation of calcium phosphate coatings appear to be justified. HA-coated implants have been shown to display signs of surface resorption which may induce foreign body reactions (de Lange et al., 1990; Buser et al., 1991; Johnson, 1992; Matsui et al., 1994; Gottlander et al., 1997). Furthermore, a recent retrospective long-term clinical study (Wheeler, 1996) on 313 HA-coated oral implants reported that the cumulative survival rate decreased to 77.8% after 8 years for HA-coated implants when compared with that of TPS-coated implants (92.7%). This may be one of the reasons why HA-coated implants are no longer the implants of choice.

(2) Submerged vs. Non-submerged Installation Techniques

Two different surgical techniques, i.e., the submerged and the non-submerged or transmucosal techniques, have been documented extensively as allowing titanium oral implants to achieve successful osseointegration and form a supracrestal soft tissue barrier (Brånemark et al., 1977; Adell et al., 1985; Berglundh et al., 1991, 1994; Buser et al., 1992; Berglundh and Lindhe, 1996; Weber et al., 1996; Cochran et al., 1997).

Animal experiments

The potential impact of installation technique as well as implant and abutment geometry on the hard- and soft-tissue structures around 3 different implant systems was studied in beagle dogs (Abrahamsson et al., 1996). The comparisons included the evaluation of implants installed by means of a submerged technique (e.g., the Astra Tech® Dental Implant System and the Brånemark System®) or a non-submerged implant placement (e.g., the ITI® Dental Implant System). The results showed that the amounts of peri-implant lamellar bone formed around the 3 implant systems were almost identical. A junctional epithelial attachment of about 2 mm in height and a zone of connective tissue attachment of about 1 mm in height were established around the 3 different abutment parts. These findings confirmed previously reported data (Berglundh et al., 1991; Buser et al., 1992) and demonstrated that hard- and soft-tissue healing around different titanium surfaces is independent of whether the implant is initially submerged (Fig. 2).

Furthermore, based on the concept of "biologic width", first introduced in periodontology in 1961 (Gargiulo et al., 1961), the influence of peri-implant soft-tissue alterations on wound healing was studied by means of two-part Brånemark System® implants in beagle dogs (Berglundh and Lindhe, 1996). At the time of abutment connection, the height of the peri-implant mucosa was maintained on one side, while on the contralateral side, the vertical dimension of the soft tissue was reduced to approximately 2 mm by means of a split flap. Following 6 months of plaque control, the animals were killed, and tissue biopsies were sampled for microscopic examination. The peri-implant mucosa on both sides showed a 2-mm-long junctional epithelium followed by a zone of supracrestal connective tissue of about 1 mm in height. Although on the right and left sides, the peri-implant mucosa was of a different thickness at the abutment connection, the resulting supracrestal soft-tissue attachment showed more or less identical dimensions. These findings suggested that at sites where the thickness of the peri-implant mucosa was reduced to ≤ 2 mm, wound healing consistently included crestal bone resorption to establish a supracrestal soft-tissue attachment totaling about 3 mm in height. Similar observations were made in a histometric analysis of the dimensions of the implant-gingival junction around clinically healthy loaded and unloaded non-submerged one-part titanium implants.
placed in foxhounds (Cochran et al., 1997). Titanium implants with TPS-coated or sandblasted and acid-etched (SLA) surfaces were placed in canine mandibles, and the tissues were allowed to heal for 3 months. Independently of the implant surface characteristics, a junctional epithelium of about 2 mm and a zone of connective tissue contact of about 1 mm formed around the neck of each implant at different time points. These results suggested the presence of a biologic width, similar to that associated with natural teeth, around both loaded and unloaded non-submerged, one-part titanium implants.

Histological evaluations of peri-implant tissue reactions to submerged and non-submerged TPS-coated and unloaded implants were undertaken in monkeys 22 weeks after healing (Gottfredsen et al., 1991). The morphometric analysis revealed no differences in the percentages of bone-to-implant contact area between submerged and non-submerged implants. Although direct bone-to-implant contact plays a key role with endosseous implants, it should not be regarded as the sole criterion for implant success. The peri-implant soft-tissue conditions may be equally important for implant stability. Indeed, an analysis of the peri-implant soft tissues around non-submerged implants, without oral hygiene during the healing period, revealed the presence of a greater number of inflammatory cells and a longer junctional epithelium migrating into infrabony defects (Gottfredsen et al., 1991). In conclusion, this study has demonstrated that submerged and non-submerged implants, installed in the same animal in similar sites, showed no difference with regard to bone-to-implant contact, suggesting that osseointegration can be achieved in one-stage as well as in two-stage surgical procedures.

We used the beagle dog model (Weber et al., 1996) to compare the tissues formed around implants installed with a submerged and a non-submerged technique. A short healing period of 6 weeks after a second-stage surgery was allowed for the implants installed with a submerged technique. Histological characteristics assessed at the light microscopy level were reported. This study showed that the apical extension of the junctional epithelium was greater and the supracrestal connective tissue portion smaller at submerged than at non-submerged implants. Using a similar experimental design, investigators have reported radiographic and histological features of submerged and non-submerged implants of the Bränemark System® in Labrador dogs (Ericsson et al., 1996). In this latter study, however, the healing period following abutment connection at the submerged implants was 3 months. No differences in the soft-tissue dimensions around both implant groups were reported. The radiographic peri-implant bone loss assessed from the time of fixture placement to the end of the experiment amounted to 2.1 mm for submerged and 2.6 mm for non-submerged implants, respectively.

The results of another radiographic evaluation of peri-implant bone changes around submerged and non-submerged implants in beagle dogs have recently been reported (Fiorellini et al., 1999). Although having different temporal patterns of peri-implant bone resorption, all submerged and non-submerged implants demonstrated bone loss during the study period, and, after 18 weeks, there were no differences in the overall amount and rate of peri-implant bone loss with the two placement modalities.

A submerged and a non-submerged installation technique with Astra Tech® implants in beagle dogs has also been reported (Abrahamsson et al., 1999). In the submerged-implant group, the time period between second-stage surgery and death was 6 months. The histological evaluation did not reveal any differences with regard to soft-tissue dimensions or supracrestal connective tissue composition. Peri-implant bone loss detected by means of standardized radiographs amounted to 0.4 mm in the submerged group.
and 0.3 mm in the non-submerged implant group. The presence of a microgap between the fixture and the abutment, as reported in another study with implants of the Brånemark System® (Ericsson et al., 1996), was used to explain the difference in peri-implant bone loss between the Brånemark System® and the Astra Tech® Dental Implant System®. This explanation is consistent with previously reported data (Ericsson et al., 1995; Persson et al., 1996), suggesting that, following abutment connection, bacteria from the oral cavity may contaminate internal surfaces and the microgap area of implants of the Brånemark System®, thus resulting in some marginal peri-implant bone loss. These observations are consistent with crestal bone changes around unloaded submerged and non-submerged one- and two-part titanium implants inserted into foxhounds (Hermann et al., 1997). Two-part implants displayed a microgap between the fixture and the abutment part. According to this study, the location of the microgap—above or below the bone crest—had a significant effect on the peri-implant bone level. The bone loss corresponded to the occurrence of the microgap at different locations (e.g., supra- and subcrestal, and at the crest) and suggested, therefore, the presence of microbial leakage in the submucosal and crestal environment.

On the other hand, the analysis by Levy et al. (1996) of the healing around submerged and non-submerged implants in beagle dogs did not agree with the findings of Abrahamsson et al. (1999). Their histomorphometric analysis revealed direct bone-to-implant contact length to be greater for submerged implants and suggested that bone healing may be delayed around non-submerged implants. It should be pointed out, however, that in this study, the submerged implants were kept in a submerged position for 6 weeks and were never exposed to the oral environment. This difference in the study design and the length of the healing period may account for the different outcomes in the two studies.

**Clinical studies**

Findings from animal experiments reported in the previous section have demonstrated that titanium implants can achieve successful osseointegration with either a submerged or a non-submerged installation modality. The aim of the clinical and radiographic study by Ericsson et al. (1994a) was to evaluate whether implants of the Brånemark System® had to be submerged initially for proper osseointegration to be achieved, and whether these implants could subsequently be used as abutments for fixed prosthodontic reconstructions. In a split-mouth design, 11 subjects with edentulous mandibles were treated on the right side by means of the original two-step surgical procedure, while, on the left side, implants were placed and abutments connected at the same session. Fixed bridgework was incorporated 3 to 4 months after implant installation. The results showed that all the clinical and radiographic parameters were similar for the two groups of placement modalities. This suggested that implants originally designed for a two-step surgical procedure may also achieve successful osseointegration when used with a non-submerged technique.

In a prospective one-year clinical study (Bernard et al., 1995), implants of the Brånemark System® were inserted by means of a one-step surgical procedure to test the hypothesis as to whether this treatment protocol may lead to successful osseointegration. In each of five patients with edentulous mandibles, 2 implants were inserted into the canine region. Three months later, spherical abutments were connected to support complete overdentures. The clinical results showed that, 9 months after being loaded, all implants presented with favorable peri-implant soft-tissue conditions, and the radiographic analysis showed an initial rate of crestal bone loss similar to that reported for a submerged implant placement. The authors concluded that a non-submerged one-step surgical placement of Brånemark implants in the mandible led to similar clinical and radiographic results as compared with a submerged two-step procedure. These preliminary results were confirmed in a prospective multicenter clinical study (Becker et al., 1997) on implants of the Brånemark System® inserted by means of a one-step surgical technique. The outcomes of this study indicated that one-step Brånemark implants inserted into the mandibles and maxillae of completely and partially edentulous patients with good bone quality and quantity provided excellent clinical and radiographic results after one year. Hence, it should be evident that transmucosal implant placement will be preferred in the future because of the decreased morbidity and substantially reduced treatment time, leading to decreased costs.

**3) Tooth-implant- vs. Solely-implant-supported Fixed Partial Dentures**

In the oral rehabilitation of partially edentulous patients, implants may serve for implant-supported or tooth-implant-supported fixed partial dentures (FPD). However, the assumption that loaded osseointegrated oral implants are ankylosic and, hence, show no mobility has led to the recommendation that rigid connections between implants and teeth should be avoided because of the risk of excessive loading of the implants (Kirsch and Ackermann, 1989). As a means of compensating for mobility discrepancies, non-rigid elements incorporated into implant supra-structures have been advocated when teeth and implants are connected. To date, there is no evidence to form the basis for such a concept. However, occasional root intrusion is seen in case reports as a potential clinical adverse effect of non-rigid connections between implants and teeth (Sheets and Earthman, 1993). The possible adverse reactions in the periodontium as a result of connecting teeth to implants have been investigated, and it appears that there are no detrimental effects on the periodontium of abutment teeth (O'Leary et al., 1992; Blancu et al., 1995). Vertical loading of tooth-implant-supported FPDs appears to be equally distributed between teeth and implants (Rangert et al., 1991, 1995; Gunne et al., 1997). Furthermore, no increased risk of stress concentrations around the implant's neck have been reported when the implant was connected to teeth (Gross and Laufer, 1997; Laufer and Gross, 1998).
The clinical relevance of this controversy has culminated in several investigations advocating either implant-supported (Sullivan, 1986; Naert, 1993; Schmitt and Zarb, 1993) or both implant- and tooth-implant-supported bridges (Ericsson et al., 1986; Krämer, 1990; Cavicchia and Bravi, 1994). In partially edentulous patients, implant installation in the posterior area of the mandible and maxilla has become a valid alternative to a removable partial denture which, in many cases, may not be well-accepted by the patient. Several research groups have focused their attention on the possibility of connecting implants to teeth and comparing the long-term results with those from implant-supported FPDs (Astrand et al., 1991; Gunne et al., 1992, 1999; Olsson et al., 1995; Brägger et al., 2001). The principal aims of a 10-year clinical and radiographic report (Gunne et al., 1999) were (1) to evaluate mandibular implant-supported vs. tooth-implant-supported FPDs, (2) to evaluate changes at the marginal peri-implant bone level, and (3) to evaluate the use of short implants (7 mm) as abutments in the posterior area of the mandible. The implant-supported FPDs were supported by 2 Brånemark System® implants, and the mixed reconstructions by the implant and the most distal tooth in the mandible (usually a canine or premolar). No differences with regard to implant failures were reported between implant-supported FPDs and combined tooth-implant-supported FPDs. The total peri-implant bone loss over 10 years of observation amounted to 0.5 to 0.7 mm and was statistically significantly less around implants of the mixed tooth-implant-supported FPDs. This observation is in agreement with changes in marginal bone levels reported in comparable studies of the same implant system (Quiroyn et al., 1992; Jemt and Lekholm, 1993; Lekholm et al., 1994). Although the difference between the two groups was small and most likely clinically irrelevant, it indicates that abutment teeth are not negatively influenced when rigidly connected to implants. After the implants had been in function for two years, there was even an increase in marginal peri-implant bone level, and this increase was more pronounced around implants connected to teeth than around implants supporting FPDs alone. A comparable increase in bone level has also been reported by Naert et al. (1992). Despite the use of short implants (7 mm), no increased failure rates were reported when this implant length was compared with 10-mm implants. A slight loosening of 5 gold screws was encountered, and, in contrast to other reports (Quiroyn et al., 1992; Jemt and Lekholm, 1993; Lekholm et al., 1994), no technical failures such as implant or retaining screw fractures were reported in this 10-year study (Gunne et al., 1999).

Biological and technical complications of tooth-implant- and solely-implant-supported FPDs after 4 to 5 years of function have recently been analyzed for the ITI® Dental Implant System (Brägger et al., 2001). Partially edentulous patients were divided into three groups according to the type of prostodontic treatment. Group A included 33 patients with 40 implant-supported FPDs, group B consisted of 40 patients with 58 tooth-supported FPDs, and group C included 15 patients with 18 mixed tooth-implant-supported FPDs. Complete failures resulted in the loss of one FPD in each group. Biological complications occurred in 9.6% of the implant abutments, with the majority of them (6.7%) demonstrating peri-implantitis lesions. For this purpose, peri-implantitis was defined as probing pocket depth ≥ 5 mm in combination with bleeding on probing and radiographic bone loss. Biological complications occurred in 11.8% of the abutment teeth, with endodontic problems (4.9%) and recurrent periodontal lesions (4.1%) accounting for the most frequent complications. As with peri-implantitis, recurrent periodontitis was defined as probing depth ≥ 5 mm in combination with bleeding on probing and radiographic bone loss. Technical complications occurred in 15.1% of the implants and in 7.1% of teeth, with the majority consisting of minor porcelain fractures which did not result in the replacement of the FPDs. Technical complications were statistically significantly more frequent on implant-supported FPDs and were significantly correlated with bruxism and with the incorporation of mesial or distal cantilevers into FPDs. In conclusion, this study has provided evidence that after 4 to 5 years of function, favorable clinical conditions were found around teeth and implants, and that complete loss of FPDs occurred at similar rates in implant-supported, tooth-supported, or mixed implant-tooth-supported reconstructions.

It appears from these longitudinal studies that both solely-implant-supported and mixed tooth-implant-supported FPDs offer fully satisfactory function and a similar degree of high predictability.

(4) Morse-taper Connection vs. Butt-joint Interfaces

Based on several reports on biomechanical implant complications of screw loosening and fracture, the need for an implant design offering some degree of biomechanical stability has been recognized to be essential (Glantz et al., 1993). Under functional conditions, osseointegrated oral implants are subjected to highly complex loads of different durations, directions, and magnitudes. In addition to load transmission at the bone-implant interface, long-term performance of FPDs is closely related to the stability of the mechanical components within the implant-abutment-crown complex. Within this complex, the design of the interfaces among implant, abutment, and crown may have a profound impact on the long-term prognosis of implant-supported prostheses.

In contrast to the butt-joint design of the Brånemark System®, 2 implant systems (e.g., the ITI® Dental Implant System and the Astra Tech® Dental Implant) have presented a novel approach to implant design, whereby the abutment is connected to the implant by an internal conical interface without the use of an abutment screw. This so-called "morse-taper connection" provides a mechanical friction grip without the possibility of rotation of the abutment. The morse-taper connection of the ITI® Dental Implant System with an internal angle of 8° results in a removal torque moment which is 10 to 20% higher than the tightening moment, whereas with a butt-joint interface, the removal torque is approximately 10% lower than the tightening moment (Sutter et al., 1993).
Furthermore, an in vitro evaluation (Norton, 1997) of implants characterized by an internal conical interface (e.g., the Astra Tech Dental Implant) revealed a statistically significantly increased resistance to bending forces when compared with implants with a hexagon-mediated butt-joint interface (e.g., the Bränemark System).

Precise fit of the mating components plays an important role in screw-loosening. Under functional loading conditions, mechanical freedom between the machined surfaces of a butt-joint, such as the external hexagon, results in vibrations and micro-movements, leading to failures of the screw-joints. Several retrospective clinical studies have reported a high incidence of screw-loosening and/or fracture associated with the two-stage external hexagon implant systems. Screw-related complications have been reported in prosthodontic treatments of both fully edentulous (Zarb and Schmitt, 1990; Lemt, 1991; Hemmings et al., 1994; Kallus and Bessing, 1994; Lemt and Lekholm, 1995) and partially edentulous patients (Lemt et al., 1992; Lekholm et al., 1994), as well as with single-tooth replacement (Lemt et al., 1990; Lemt, 1991; Becker and Becker, 1995). Furthermore, screw loosening has also been reported for a dental implant system based on the morse-taper concept, such as the ITI® Dental Implant System. In a retrospective analysis of ITI® implants used for single-tooth replacement, an incidence of 8.7% occlusal screw-loosening without repeated loosening was reported after 6 or more months of loading (Levine et al., 1997). These studies clearly indicate that the fixation of a FPD by occlusal screws represents a potential hazard for the longevity of a fully functional prosthesis. Hence, it is evident that cementation of FPDs onto implants may dramatically reduce such technical complications.

(5) Titanium Abutments vs. Esthetic Abutments

In recent years, increasing esthetic demands in implant dentistry have become an important issue, and implant manufacturers have started to offer abutments of different designs and materials to meet these higher standards. The principal aim of an experiment in beagle dogs (Abrahamsson et al., 1998) was to examine if the material used in the abutment part of an implant system could influence the quality of the surrounding soft-tissue barrier. Fixtures of the Bränemark System® were made of commercially pure titanium, and abutments inserted at the second-stage surgery were made of either commercially pure titanium, highly sintered aluminum-based ceramic (Al₂O₃), gold alloy, and fused-to-gold dental porcelain. A careful plaque control program was instituted, and soft-tissue healing was allowed for 6 months. The findings of this study demonstrated that the abutment material was of paramount importance for the location and quality of the attachment that occurred between the soft tissue and the implant. Abutments made of commercially pure titanium or aluminum-based ceramic (Al₂O₃) were associated with similar soft-tissue healing conditions and the formation of a physiological epithelial and connective tissue attachment to the abutment. On the other hand, at sites where abutments made of gold alloy or dental porcelain were inserted, there was no proper soft-tissue attachment to the abutment. As a consequence, the soft-tissue margin receded, and bone resorption occurred. These observations confirm previous, findings from animal experiments and clinical trials with single-crystal sapphire implants (Akagawa et al., 1989; Fartash et al., 1990; Arvidson et al., 1991, 1996).

In areas of esthetic priority, it appears more favorable for peri-implant soft tissues to be manipulated and adapted by careful implant placement (i.e., slightly more submerged than ordinarily), soft-tissue conditioning with appropriate provisional restoration and observation of a correct emergence profile of the crown with optimal marginal precision of the reconstruction, rather than by a choice of porcelain abutments (Belser et al., 1998). It must be emphasized that all of these esthetic concepts must be validated in prospective longitudinal clinical trials.

Concluding Remarks

In the past decade, implant therapy has expanded to become a routine procedure in clinical situations with sufficient bone volume. This has considerably changed established treatment concepts.

The increased predictability of implant systems may be attributed to knowledge obtained from animal and human studies which have led to clinicians' comprehensive understanding of the systems' biological and technical aspects. Commercially pure titanium has become the material of choice in implant dentistry, and several attempts have been made to improve implant anchorage in bone by modifying the surface configurations, thereby shortening the healing period and allowing for earlier functional loading. Attempts at further simplification of the clinical procedures are also increasing. In recent years, trends have emerged toward the utilization of a non-submerged implant installation technique and shorter implants. The installation of shorter implants, for example, may avoid the need for sophisticated surgical procedures such as mandibular nerve transposition or sinus floor elevation. Today, implant therapy has reached the goal of attaining highly predictable long-term results in standard clinical situations. However, challenges for the future include the refinement of surgical and technical treatment modalities for selected situations such as compromised or esthetically demanding sites.

Acknowledgment

This review was prepared with the financial aid of the Clinical Research Foundation (CRF) for the Promotion of Oral Health of the University of Berne, Switzerland.

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