Tooth-to-Implant Connection: A Systematic Review of the Literature and a Case Report Utilizing a New Connection Design

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ABSTRACT

Background: In the treatment of partially edentulous patients, implants have often been connected to natural teeth. Numerous studies have reported significant complications and problems, while others have demonstrated favorable outcomes.

Purpose: The purpose of this article was to systematically review the literature regarding the splinting of implants and teeth. The difference in the biomechanical behavior between osseointegrated implants and teeth and the efficacy of the different modes of connection that have been employed are explored.

Materials and Methods: A MEDLINE search between 1966 and October 2006 was performed to retrieve relevant articles. A further manual search from the bibliographies of the former articles was performed to include as many references as possible. Prospective and retrospective clinical studies, as well as laboratory and computer-generated research, were included.

Results: A pronounced difference in the biomechanics of teeth and implants has been revealed in theoretical models. This disparity has also been supported by the majority of the experimental work published. As a result, principal complications, such as intrusion of teeth and higher risk of overload and greater marginal bone loss around the implants have been reported. Among the several types of connections utilized, the rigid connection showed fewer complications but unfortunately did not eliminate them.

Conclusion: Totally implant-supported prostheses should be the treatment of choice. However, there are cases where combining teeth and implants is inevitable. The authors propose a rationale design of connecting implants and teeth. This design minimizes the biologic and technical complications.

KEY WORDS: combination fixed partial dentures or bridges, dental implants, dental prosthesis design, intrusion, non-rigid attachment, partial edentulism, tooth and implant connection

INTRODUCTION

The introduction of osseointegrated implants in North America was supported by multicenter studies from Scandinavia, showing high success rates in the treatment of completely edentulous jaws.[1–3] The predictability of this treatment modality led to the exploration of the potential applications. Since 1982, the indications expanded to the treatment of partial edentulism.[4] Numerous studies have proven the efficacy of implants in dentate patients.[4–11]

According to the recommendations of the Swedish National Board of Health, implant- and tooth-supported restorations were to receive occlusal stresses independently from each other.[5] Contrary to this guideline and strictly for research purposes, a small number of prostheses combining implants and teeth were fabricated. After a limited observation time, some fixtures, especially those closest to the natural teeth, suffered from pronounced marginal bone loss and even loss of integration.[5] This raised the question of whether a tooth with its periodontal ligament (PDL) can efficiently provide support in a tooth-implant restoration.

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It was the purpose of this article to systematically review the literature available regarding the connection of implants and teeth and recommend a design concept that can minimize biologic and technical complications.

METHODS AND MATERIALS

A MEDLINE search between 1966 and October 2006 was performed to retrieve relevant articles. The search included articles published in the dental literature in English. The key words used were dental implants, dental prosthesis design, partial edentulism, tooth and implant connection, combination fixed partial dentures (FPDs) or bridges, intrusion, nonrigid attachment, and combinations of these terms. The search was completed manually from the references of the former articles.

No randomized controlled clinical trials were identified in the literature. The inclusion criteria incorporated all prospective and retrospective clinical studies, as well as laboratory and computer-generated research. If patients were involved, a clinical examination had to be undertaken. Articles based on questionnaires or patient records only were excluded. Abstracts, opinion articles, and techniques were excluded as well.

An analysis was carried out regarding the divergence in the biomechanical behavior between natural teeth and osseointegrated implants. Several methods of connection have appeared in the literature as a solution to this problem. The published data on each of these methods were examined in order to estimate their efficacy. Among the numerous complications being reported, tooth intrusion was the most significant. A comprehensive investigation was performed to discover its mechanisms and etiology.

FINDINGS

Biomechanics of Natural Teeth and Implants

Combining implants and teeth creates a potential biomechanical mismatch of the supporting units. Natural teeth are attached to the bone indirectly via the periodontal ligament. This ligament provides a physiological horizontal mobility in the range of 150 to 200 μm.[12] In the presence of periodontal disease, this tooth movement can increase by 10-fold. Conversely, implants are rigidly anchored to the bone. Their mobility ranges from 17 to 66 μm in horizontal direction.[13] Any movement is the result of the inherent resiliency of the bone[14] and the flexibility of the prosthetic joints and components.

In addition, teeth and implants display different patterns of mobility under physiological stress. Teeth display a two-stage movement. The first stage is rapid, within the confines of the periodontal ligament, while the second is more linear.[13–15] Implants, as a result of the lack of a ligament, do not demonstrate the initial rapid displacement but move proportionately to a load in a linear fashion, apparently because of deformation of the bone. This movement varies, depending on the location within the arches. Implants in the anterior mandible demonstrate smaller values than implants in other locations[13] because of the quality of the bone. The presence of the aforementioned rapid initial movement seen on teeth and the lack of it regarding implants has a significant impact on movement under stress. Even under small forces (<20 N), the structure of the PDL will allow a tooth to intrude about 50 μm,[16] while an implant, under a force of 20 N, will only intrude 2 μm.[13] Compared with that of a tooth, the resilience (resistance to yield) of a titanium implant is calculated to be 10 to 100 times higher.[15] Additionally, the load duration and not just the magnitude of the force has a significant influence on the stress transferred to the bone around an tooth.[17] This is because of the viscoelastic nature of the PDL and the resultant tissue creep, and it is more important in bruxing patients.

The significance of this difference has to be analyzed from a clinical perspective. On one end of FPDs combining natural teeth and implants, are the teeth and their respective PDLs. Jemt and colleagues[5] stated, “while the teeth may then be expected to contribute to the support of the prosthesis, in function the abutment teeth may act as pontics in relation to the osseointegrated fixtures because of the periodontium.” Therefore, in order to distribute stresses evenly, the flexibility of the teeth must be similar to that of the implant-bone-joint system. When such prosthesis is planned, the teeth must be periodontally healthy. Splinting can be utilized to further decrease the individual tooth mobility and approach that of the implants.[4] Nonetheless, the series of adverse sequelae associated with splinting of natural teeth should be carefully considered before routinely implemented.[18] Increased mobility of the natural tooth abutments would result in an increased load to the implant.[19,20] The restoration might behave like a cantilevered FPD, with the implants as the exclusive supporting unit.[4] The risk of overloading of the implants and/or the surrounding bone becomes a concern.[19]

On the other end of such restorations, the supporting unit consists of the osseointegrated implants and the prosthetic components. The screw-joint flexibility of an external hexagon implant has been calculated in vivo.[21,22] Three-unit FPDs rigidly combining implants and natural teeth were examined. The implants received a transmucosal abutment. Consequently, the studies determined the synergistic behavior of both joints. The results indicated that the flexibility of the implant system matched the axial flexibility of the periodontal ligament. Therefore, the tooth was able to actively support the prosthesis. However, it was shown that the implant components have to bend in order for the load to be shared between the supporting units,[22] and, in some patients, the implants received 2.5 to 4 times higher load than the abutment teeth.[21] Geometrically, the closer the implant is to the tooth, the higher the bending moment of the implant joint.[19,20] "If the components of the implants are subjected to repeated bending, this could lead to screw loosening or, even worse, metal fatigue and eventual fracture of an implant component."[20]

Methods of Connection

To overcome the potential problems, various methods of connection have been presented in the literature. The techniques range from resilient components within the implant prosthesis to nonrigid and rigid attachments.

Because teeth are not ankylosed into the bone, a mechanism that increases implant mobility would potentially solve the problem. One design incorporates a flexible component that simulates the periodontal ligament. An "intramobile element" (IME), interposed between the abutment and restoration, is used when splinting to adjacent teeth is desired.[23] Theoretical and limited in vivo data on the use of the resilient element indicate that there is a damping of the occlusal force on the implant compared with a rigid titanium component in freestanding implants[11,24] and a more uniform stress distribution to the bone around the implant only in tooth-implant FPDs.[25] On the contrary, photoelastic experimentation reveals that the use of the IME does not allow for more deflection of the restoration when compared with a rigid component. The stress patterns in the simulated bone are equal for both elements, suggesting that the stresses are transferred to the titanium-retaining screw.[26] The deformation of the IME does not provide the implants with elasticity similar to that of a natural tooth,[27] and, therefore, the bending moments that develop on implants carrying this abutment are nearly twice as high as physiological bending moments during mastication.[28] Unfortunately, well-controlled experimentation and clinical trials are lacking to show the efficacy of the system. Another major drawback is the need for frequent replacement of the resilient component because of wear, fatigue,[23] and fracture.[29]

Utilizing nonrigid connection systems is another approach to evenly distribute the load transfer.[30–33] The rationale is that key and keyway attachments, with the matrix on the tooth side, would allow physiological tooth movement independent from the implant. The concept looks promising, but the in-vitro data are equivocal. Finite-element analysis (FEA) studies are ambiguous probably because it is impossible to reproduce all the details of natural behavior in computer simulations.[17] One such study confirms the stress-breaking action of the nonrigid connector, illustrating reduction of stresses within the implant by a factor of 24 when the force is applied on the tooth side.[34] On the contrary, another FEA concludes that the differences in stress distribution are minimal whether or not an attachment is used.[35] The latter conclusion is supported also photoelastically.[36] Regarding the tooth, it seems that its movement patterns are not significantly influenced by the mode of connection.[37] From a clinical perspective, there are several trials that have used a connection employing an attachment successfully.[31,33,38,39] An unpleasant complication that has been observed is intrusion of the natural tooth segment[20,31,40–44] (Figure 1).

Several theories have been described to explain the phenomenon of intrusion.[40,41] The ratchet effect is one

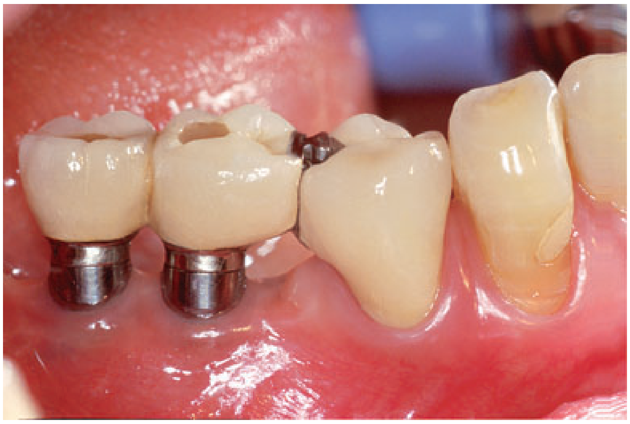

Figure 1 Intrusion of natural tooth #28 connected to implants #29 and 30 via a semi-precision attachment. Discrepancy between matrix and patrix is evident.

of the hypotheses. It is described as mechanical binding between the matrix and the patrix of precision and semiprecision attachments that prevents the tooth to return to its natural position. Debris microjamming within the attachment acts in the same way. A vicious cycle is formed, where intrusion is progressively increasing. Debris impaction has been documented in cases with telescopic copings as well.[45] However, it is questionable whether it is the cause of the intrusion or just plaque accumulation after a space is created between the coping and the superstructure. The impaired rebound memory of the PDL of the tooth is assumed to act independently or as a contributing factor to the above mechanisms. The presumption is that the PDL is continually depressed in the socket under the occlusal forces. This causes remodeling of the PDL and orthodontic tooth movement in order to reduce the constant trauma.[46,47] Furthermore, flexure of the FPD framework and flexure of the mandible[48–51] are associated with intrusion of tooth abutments. However, intrusion has been reported for maxillary arches as well,[20,52] suggesting that mandibular flexion is at best of secondary importance. Regarding the metal framework, an in vivo strain study indicated contraction deformation of the framework in both rigid and nonrigid connections. With a prolonged period of loading, these strains could result in intrusion of the natural tooth.[53]

The use of telescopic copings and superstructures is an alternative means to connect teeth and implants.[54] In this case, there is no direct contact of the natural tooth to the opposing occlusion. Unfortunately, intrusion is still observed.[41,55] Theories to explain this phenomenon include disuse atrophy of the periodontium[56,57] and a stress wave theory.[45,58] Disuse atrophy of the PDL does not seem to explain the intrusion phenomenon. Teeth in hypofunction tend to supererupt rather than sink into their sockets. The stress wave theory deals with the high energy absorbed by a tooth connected to an implant, under occlusal forces. Theoretically, the stress waves activate osteoclastic activity, resulting in intrusion of the tooth. A suggested solution to the problem is the incorporation of a vertical-locking screw in the cemented coping.[59]

A last group of investigators employ rigid connections between implants and teeth.[31,32] When fabricating one-piece prostheses, the moments are minimal when both supports have similar mobility. Because this is not the case for implant-tooth FPDs, the moment becomes higher for the implant when the load is on tooth side.[60] Photoelastic and finite element calculations confirm that, by a rigid connection, the implant receives higher stresses than the tooth.[36,61] The stresses become worse for the implant as the number of pontics increases, indicating that the prosthesis in mainly supported by the implant.[61] From a clinical perspective, the short-term survival of the restorations seems similar to implant-supported FPDs. At 24 months after delivery, although an increase in load participation for the implants is demonstrated, the marginal bone level of the implants is stable.[62] Other clinical studies adopt these favorable findings of successful implant-tooth FPDs[63] and show similar or even smaller marginal bone loss around the implants compared with implant-to-implant restorations.[64,65] There is only one long-term prospective evaluation that reports positive results of well-functioning FPDs and higher marginal bone level for implants rigidly attached to teeth. Contributing factors to the success is the interpositioning of a standard abutment, which increases the flexibility of the implant, and the complete removable dentures as opposing occlusion, reducing the bite forces.[66–68] In the aforementioned studies, intrusion of teeth has not been observed. More recent studies, with longer follow-ups, demonstrate intrusion phenomena even with rigid connection[69,70] and greater bone loss compared with implants nonrigidly attached to teeth.[69,71]

DISCUSSION

There are numerous reasons that authors advocate the joining of teeth and implants. The most common indication is anatomic limitations in the posterior areas, where there is insufficient bone housing for implants.[30,32] Therefore, when the implant segments are not self-sustained, either because of inadequate number or very short implants, it might be necessary to fabricate a mixed prosthesis.[72] Other reasons include scenarios with failed implants with some remaining implants and financial considerations for additional placement of implants and surgical augmentations in order to achieve completely implant-supported restorations. In addition, it is thought that the tooth will provide additional support for the restoration[30] and increase the antirotational resistance of the screw joint.[20] Finally, in periodontally compromised cases, the implants can provide stabilization of the teeth.[33,54,73]

The subject is very controversial. There are three main schools of thought. One school advocates nonrigid connection mechanisms to overcome this difference in mobility.[30,33,54] Another prefers a rigid connection because of the decreased frequency of mechanical failures.[31,32] The third recommends that implants and teeth should not be connected. The most up-to-date publications show a higher need of maintenance and repair when combining teeth and implants than the implant free-standing solution.[70,71,74]

From a theoretical point of view, nonrigid connection with the matrix at the tooth side appears advantageous. Biomechanically, it would allow for physiological movement of the tooth under occlusal forces and provide at least some support for the restoration.[30] Unfortunately, clinical experience correlates this type of connection with intrusion of the natural tooth[20,31,40–45,52,55,70,71,74] and frequent emergency appointments.[70] Intrusion reduces abutment support, leading to an increase in cantilever stresses to the implant and supporting bone and possibly allow migration of the opposing teeth.[36] This phenomenon is not only observed on single teeth, but sometimes even a multiple-tooth segment may intrude.[29,72] Semiprecision attachments might be advantageous in periodontally involved teeth compared to teeth with normal support. One study showed intrusion only of periodontally healthy teeth joined to implants either with a sliding attachment or a telescopic coping. No standardized radiographs were taken, though, to assess the potential overload to the implants.[52] However, when treatment planning, one should bear in mind that "the implants support the teeth and not the other way around."[75]

Because of the fewer complications, a rigid type of connection has proven to be more successful. The differential mobility between teeth and implants is in the range of 5 : 1, thus producing significant torque on the implants.[75] The advocates acknowledge the biomechanical challenge and try to minimize it by appropriate case selection. The periodontal support and the long-term prognosis of the tooth must be excellent.[20] The implant system used must allow for some degree of flexibility within its screw joint. For external hexagon implants, the screw joint movement is comparable to a natural tooth[19,21,22,76] and there are some data indicating that the magnitude of stresses around an implant is similar whether or not a transmucosal abutment is used.[77] Ideally, the tooth should not be immediately adjacent to the fixture to minimize bending moments of the joint.[19,20] The design of the FPD should allow for minimal movement in a buccolingual direction.[16,19] A histological study in the canine model shows no deleterious effects to the periodontium of the natural tooth, rigidly attached to an implant.[78]

Nevertheless, not all problems are solved when implants and teeth are rigidly joined. Intrusion is still a great concern. Its occurrence ranges from 3.5 to 44%.[41,42,70] Marginal bone loss is estimated to be threefold compared with freestanding implant restorations and nonrigid tooth-to-implant prostheses.[71] Finally, the results of another study demonstrate a threefold increase in late implant failure risk in comparison to implant-to-implant and nonrigid implant-to-tooth connection.[4] Unfortunately, no statistical analysis substantiates the findings of the latter clinical trial.

The data deriving from two meta-analyses provide the best evidence of the comparative success of freestanding and combined FPDs.[79,80] Meta-analysis of implant-supported FPD studies demonstrates implant survival rate of 95.4% at 5 years and 92.8% at 10 years. The respective FPD survival rate is 95% at 5 years and 86.7% at 10 years.[79] In tooth-implant-supported restorations, the survival of implants is 90.1% at 5 years and 82.1% at 10 years. The survival of FPDs is 94.1% at 5 years and 77.8% at 10 years.[80] Significantly higher annual failure rate is seen with implants combined with teeth versus freestanding implants (1.33% vs. 0.51%). The FPD failure rates in the two studies are similar at 5 years but significantly different at 10 with 22.2% failures in the tooth-implant group and 13.3% in the solely-implant group. After 5 years, implant fractures total 0.4% for the implant-supported restorations and 0.9% for the tooth-implant restorations. Intrusion is almost entirely observed with nonrigid type of connections or with rigid connection after fracture or loosening of the rigid connection and is estimated at 5.2%. Finally, screw loosening is observed in 7.3% of the implant cases and up to 26.4% in the implant-tooth cases.

It is evident that joining natural teeth to implants is accompanied by a wide range of adverse sequelae. Complications involve both teeth and implants. Intrusion of the natural tooth[20,31,40–45,52,55,70,71,74] is very disturbing for the patient and extremely difficult to solve for the clinician. Two case reports demonstrate that partial reversal of the intrusion is possible.[20,45,58] However, the efficacy and long-term results of such attempts are unknown. Lack of support from the tooth, as evidenced by implant fracture, and reintrusion are still a concern.[58] Caries due to decementation of the prosthesis,[81] root fractures,[70] and periapical periodontitis[74] are also described. Regarding the implants, loss of integration, more pronounced bone loss,[71] fixture fracture,[74,81] and technical failures involving loose screws and loose and or fractured abutments are illustrated. Implant fracture is a catastrophic failure, having functional, restorative, surgical, and emotional implications.[82] There are several reports of implant fracture when connected to a tooth.[10,74,81,82] Examination of one such implant under a scanning electron microscope shows striations on the surface. These are indicative of fatigue failure as a result of unfavorable loading conditions[82] and are similar to striations found when implants were fatigue fractured under laboratory conditions.[83] In the short-term follow-up, the potential for failure is not as apparent.[84] However, in the long term, the freestanding implant prosthesis shows significantly lower biologic and technical complications than implant-to-tooth connected restoration.[74,81]

Although totally implant-supported, FPDs are more predictable. There are instances where the clinician must consider a restoration combining implants and teeth. Cohen and Orenstein[85] propose a solution to the problem. A slot type nonrigid connector is used. The difference is that the matrix is placed on the implant side rather than the tooth side. A revision of this technique is utilized by the authors. The following case report will illustrate the preferred method of connection.

CASE REPORT

A 72-year-old male patient presented with a three-unit FPD spanning from teeth #18 to 20 (Figure 2). Tooth #18 was hemisected with poor periodontal prognosis, and #19 was missing. Tooth #20 was restored with a complete veneer gold crown. Radiographically, the tooth showed good periodontal support. The radiolucency in the periapical area of this tooth was the mental foramen, as confirmed by computer tomography (Figure 3). The tooth tested vital. The treatment plan consisted of removing the molars on this sextant and placing two implants in areas #18 and 19 in a one-stage approach. A new single crown for tooth #20 would be fabricated.

After extraction and healing, the implants were placed and were left to integrate with healing abutments. Unfortunately, the patient experienced repeated implant failures in the area of #19; this has been described as cluster failures.[86] At the impression appointment, it was determined that implant #19 was failing. It was replaced by a new implant, but it also failed to integrate. After this failure, the solution was to place an implant in the third molar position and cantilever a pontic mesially. Unfortunately, this implant exfoliated as well. A fourth attempt was made in site #19 with a similar outcome

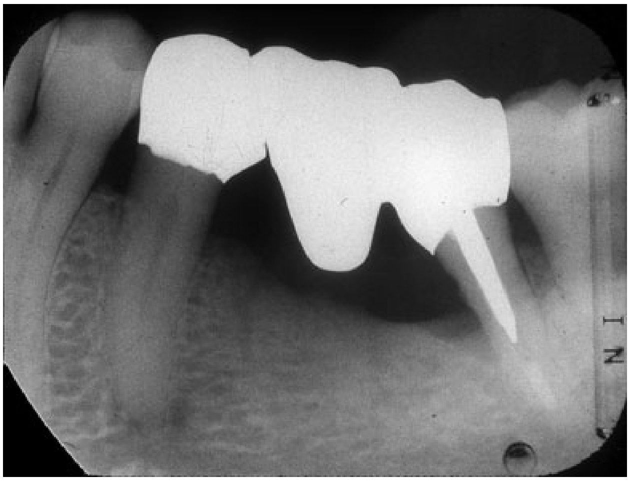

Figure 2 Tooth #18 is hemisected with poor periodontal support. Tooth #20 is restored with a gold crown. Note that the mental foramen is superimposed to the apex of tooth #20. The tooth has been tested vital before and after the treatment.

Figure 3 CT scan cut running through tooth #20. The mental nerve exits right below its apex.

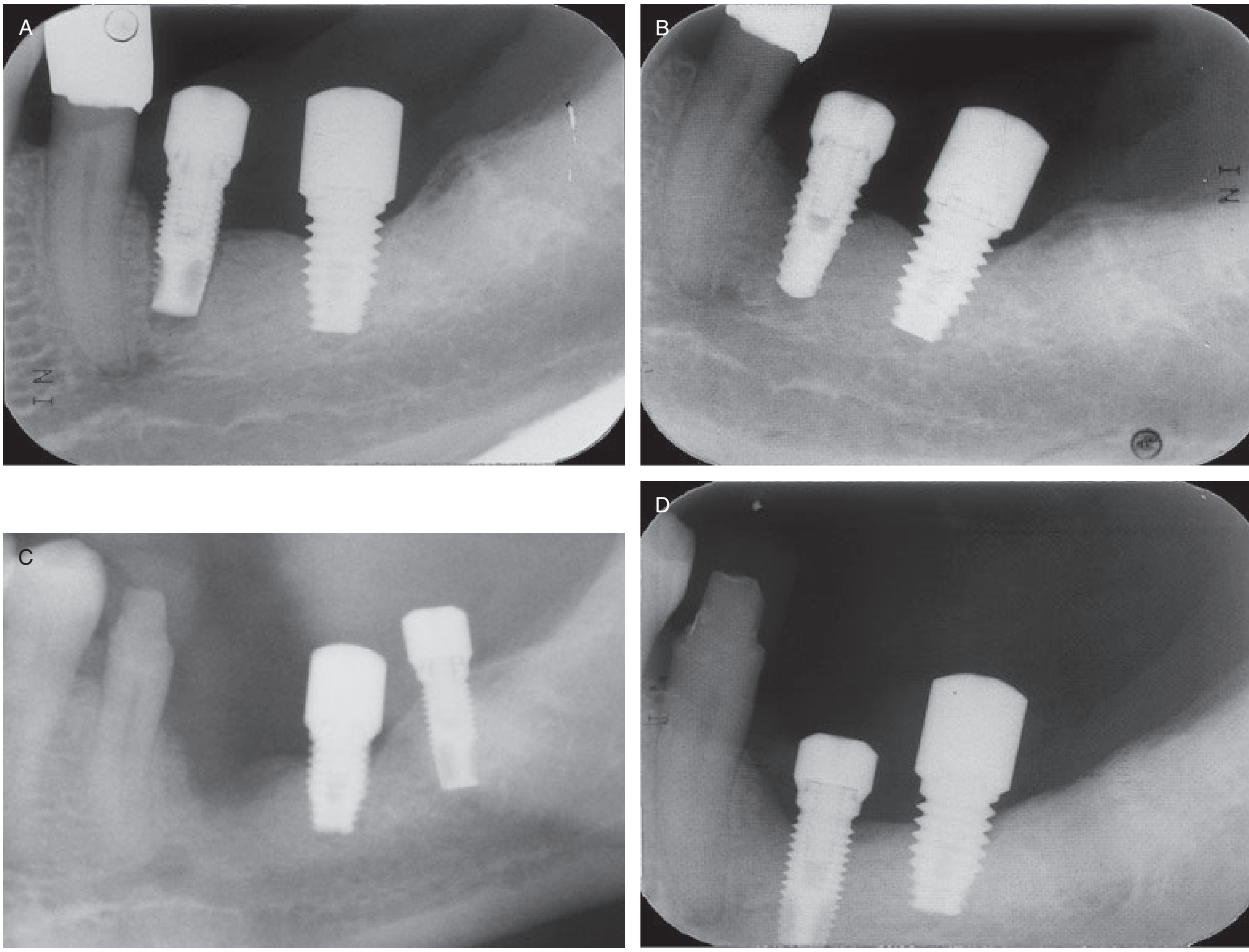

Figure 4 *A–D*, Radiographs of four consecutive implants that were placed and subsequently failed. *A*, Radiograph of implant #18, 4 months after placement. The bone remodeled at the second thread of the implant. *D*, Radiograph of implant #18, 16 months after placement without occlusal loading. The bone level is just below the second thread.

(Figure 4, A–D). Implant #18 integrated successfully since its initial placement. It was placed supracrestal to the bone to avoid injury to the mandibular nerve. At 4 months after placement, the bone level was just above the second thread of the implant (see Figure 4A), and, at 16 months, without occlusal loading, the bone remodeled just below the second thread (see Figure 4D). The implant's position was too far to the buccal. Fortunately, this area presented no esthetic concern and therefore did not have negative impact on the final outcome.

The treatment options were limited. A removable prosthesis was ruled out, as a primary motivation of treatment was to have fixed prosthesis. Cantilevering molar #19 from single implant #18 was precluded from a biomechanical standpoint. There was significant risk of overloading the implant and/or the screw joint. The patient would not accept an edentulous segment in the area of tooth #19. The remaining option was to connect implant #18 to tooth #20.

The design included a telescopic coping over the tooth, a single crown over the implant and a superstructure connecting the implant to the tooth via a nonrigid connector. The nonrigid connector was of a deep spoon-shaped rest and rest seat type. The rest seat was prepared on the mesial of the implant crown #18 (Figure 5). The corresponding rest was incorporated on the distal of pontic #19. The pontic was rigidly connected to the superstructure (Figures 6 and 7).

From a technical perspective, the rest seat was carved in the same path of insertion as the long axis of the prepared tooth #20. The rest seat allowed sufficient space, at least 1.5 to 2 mm, for strength of the patrix and a positive contact toward the center of the crown in order to achieve axial transfer of stresses (see Figure 7). This contact was confirmed clinically with the use of a polyvinylsiloxane-disclosing material (Fit Checker, GC, Tokyo, Japan). All walls were rounded to allow freedom of movement for the tooth-pontic

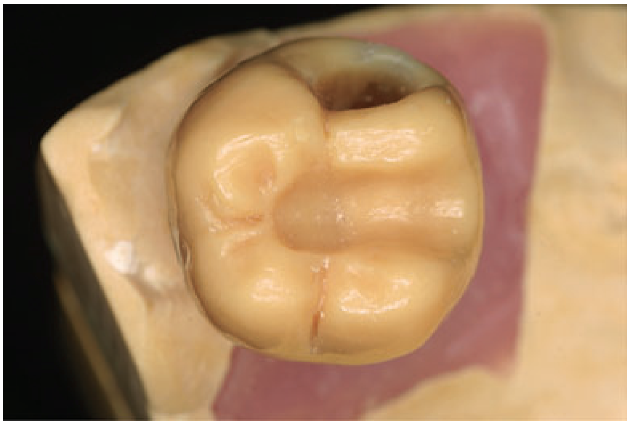

Figure 5 Rest seat carved in the wax pattern to allow axial transfer of loads and adequate strength for the rest.

piece (see Figure 5). The dimensions of the coping and superstructure were kept to a minimal in order to avoid endodontic therapy or an overcontoured restoration.

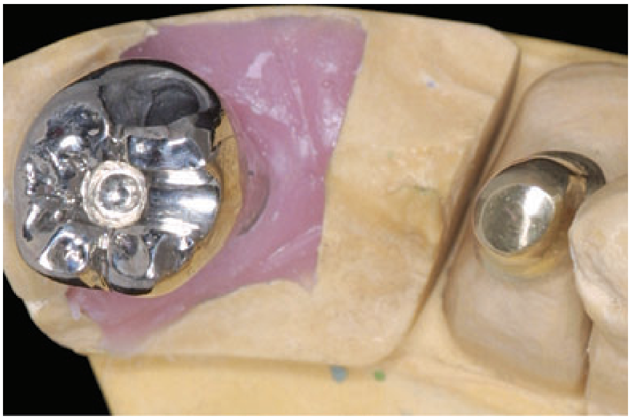

Figure 6 Telescopic coping on tooth #20 and single crown with mesial rest seat on implant #18.

Figure 7 Superstructure in place. Intimate fit of the components of the nonrigid connector is apparent.

Figure 8 Implant-supported crown #18 delivered and torqued to 32 Ncm. Telescopic coping sandblasted and permanently cemented with resin modified glass ionomer cement.

The telescopic coping was permanently cemented with resin-modified glass ionomer cement (FujiCem, GC, Tokyo, Japan) (Figure 8). The superstructure was cemented over the coping using a temporary zinc-oxide eugenol type of cement (Temp Bond, Kerr, Orange, CA) (Figures 9 and 10). At the 1-year follow-up, the bone level appeared stable at the level of the second thread (Figure 11).

There are multiple advantages associated with this design. It allows retrievability of the superstructure and subsequently of the screw-retained implant restoration. From a biomechanics standpoint, when forces are applied to the implant restoration, the stresses are taken by the implant itself. Forces on the pontic site will be distributed between the tooth and the implant, possibly resulting in a greater movement of the tooth than that of the implant as a result of the presence of the PDL and

Figure 9 Superstructure in place. Temporary zinc-oxide eugenol cement was used.

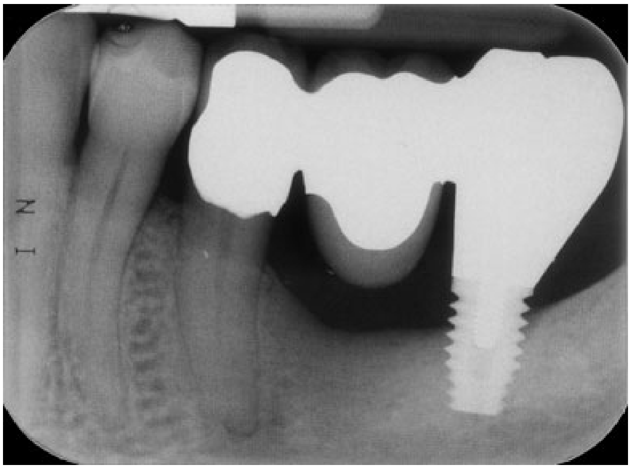

Figure 10 Radiograph of the definitive prosthesis in place at the time of delivery. The bone level was just below the second thread.

nonrigid connection between tooth and implant. Finally, when forces are applied to the tooth, the tooth receives no more force than a tooth-borne FPD abutment. The connector allows for free movement of the tooth under occlusal forces. This design has been used at our institution in the few cases in which tooth-to-implant connection cannot be avoided. Since 1990, eight such prostheses have been fabricated. No intrusion of teeth has been observed.

CONCLUSION

The consensus of the literature is for the freestanding implant prostheses over any other means of connection.[4,20,40,42–45,55,71,72,74,80,81,87] The real cause of

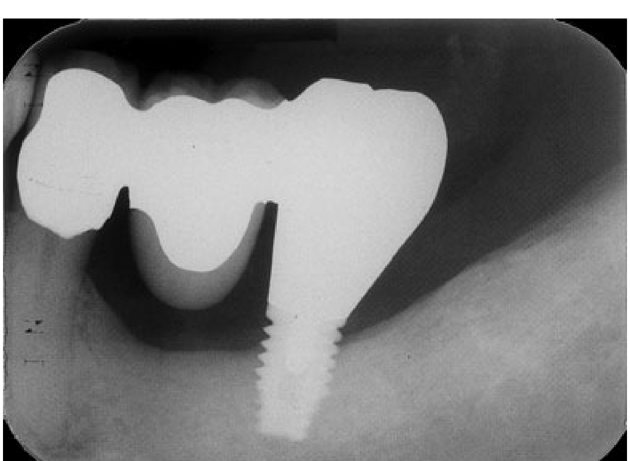

Figure 11 Radiograph of the definitive prosthesis in place 1 year after delivery. The bone level was at the level of the second thread.

intrusion remains unknown,[41,43] and only speculations have been presented. Unless the cause is determined, no etiologic solution to the problem can be given.

Combining osseointegrated implants with natural teeth should only be performed as a last resort. A risk-benefit analysis and anticipated complications should be presented to the patient and appropriate consent obtained before the treatment plan is finalized. For these limited cases, a design concept of joining implants and teeth has been presented. This proposed design rationally addresses the problems of bending forces to the implant as a result of cantilevers and intrusion of the tooth. More importantly, it allows loads to be shared between tooth and implant abutments, which is not the case in other designs. This concept takes into consideration both issues of natural tooth intrusion and implant overloading.

REFERENCES

1. Adell R, Lekholm U, Rockler B, Bränemark PI. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981; 10:387–416.
2. Bränemark P-I, Hansson B, Adell R, et al. Osseointegrated implants in the treatment of the edentulous jaw. Experience from a 10-year period. Scand J Plast Reconstr Surg 1977; 11(Suppl 16):1–132.
3. Adell R. Clinical results of osseointegrated implants supporting fixed prostheses in edentulous jaws. J Prosthet Dent 1983; 50:251–254.
4. Naert I, Quirynen M, van Steenberghe D, Darius P. A six-year prosthodontic study of 509 consecutively inserted implants for the treatment of partial edentulism. J Prosthet Dent 1992; 67:236–245.
5. Jemt T, Lekholm U, Adell R. Osseointegrated implants in the treatment of partially edentulous patients. A preliminary study on 876 consecutively placed fixtures. Int J Oral Maxillofac Implants 1989; 4:211–217.
6. van Steenberghe D. A retrospective multicenter evaluation of the survival rate of osseointegrated fixtures supporting fixed partial prostheses in the treatment of partial edentulism. J Prosthet Dent 1989; 61:217–223.
7. Lekholm U, Gunne J, Henry P, et al. Survival of the Branemark implant in partially edentulous jaws: a 10-year prospective multicenter study. Int J Oral Maxillofac Implants 1999; 14:639–645.
8. van Steenberghe D, Lekholm U, Bolender C, et al. The applicability of osseointegrated oral implants in the rehabilitation of partial edentulism: a prospective multicenter study on 558 fixtures. Int J Oral Maxillofac Implants 1990; 5:272–281.
9. Lill W, Thornton B, Reichsthaler J, Schneider B. Statistical analyses on the success potential of osseointegrated

implants: a retrospective single-dimension statistical analysis. J Prosthet Dent 1993; 69:176–185.
10. Pylant T, Triplett RG, Key MC, Brunsvold MA. A retrospective evaluation of endosseous titanium implants in the partially edentulous patient. Int J Oral Maxillofac Implants 1992; 7:195–202.
11. Lindh T, Gunne J, Tillberg A, Molin M. A meta-analysis of implants in partial edentulism. Clin Oral Implants Res 1998; 9:80–90.
12. Mühlemann HR, Zander HA. Tooth mobility: a review of clinical aspects and research findings. J Periodontol 1967; 38:686.
13. Sekine H, Komiyama Y, Hutta H, Yoshida K. Mobility characteristics and tactile sensitivity of osseoIntegrated fixture-supported systems. In: van Steenberghe D, ed. Tissue-integration in oral and maxillofacial reconstruction. Exerpta Medica, Amsterdam: Elsevier, 1986:326–332.
14. Mühlemann HR, Zander HA. Tooth mobility (III). The mechanism of tooth mobility. J Periodontol 1954; 25:128–137.
15. Richter EJ. Basic biomechanics of dental implants in prosthetic dentistry. J Prosthet Dent 1989; 61:602–609.
16. Picton DCA. The effect of external forces on the periodontium. In: Melcher AH, Bowen WH, eds. Biology of the periodontium. London: Academic Press, 1969:385.
17. Menicucci G, Mossolov A, Mozzati M, Lorenzetti M, Preti G. Tooth-implant connection: some biomechanical aspects based on finite element analyses. Clin Oral Implants Res 2002; 13:334–341.
18. Faucher RR, Bryant RA. Bilateral fixed splints. Int J Periodontics Restorative Dent 1983; 3:8–37.
19. Lundgren D, Laurell L. Biomechanical aspects of fixed bridgework supported by natural teeth and endosseous implants. Periodontol 2000 1994; 4:23–40.
20. Chee WW, Cho GC. A rationale for not connecting implants to natural teeth. J Prosthodont 1997; 6:7–10.
21. Rangert B, Gunne J, Glantz PO, Svensson A. Vertical load distribution on a three-unit prosthesis supported by a natural tooth and a single Branemark implant. An in vivo study. Clin Oral Implants Res 1995; 6:40–46.
22. Gunne J, Rangert B, Glantz PO, Svensson A. Functional loads on freestanding and connected implants in three-unit mandibular prostheses opposing complete dentures: an in vivo study. Int J Oral Maxillofac Implants 1997; 12:335–341.
23. Babbush CA, Kirsch A, Mentag PJ, Hill B. Intramobile cylinder (IMZ) two-stage steointegrated implant system with the intramobile element (IME): part I. Its rationale and procedure for use. Int J Oral Maxillofac Implants 1987; 2:203–216.
24. Chapman RJ, Kirsch A. Variations in occlusal forces with a resilient internal implant shock absorber. Int J Oral Maxillofac Implants 1990; 5:369–374.
25. van Rossen IP, Braak LH, de Putter C, de Groot K. Stress-absorbing elements in dental implants. J Prosthet Dent 1990; 64:198–205.
26. McGlumphy EA, Campagni WV, Peterson LJ. A comparison of the stress transfer characteristics of a dental implant with a rigid or a resilient internal element. J Prosthet Dent 1989; 62:586–593.
27. Lill W, Matejka M, Rambousek K, Watzek G. The ability of currently available stress-breaking elements for osseointegrated implants to imitate natural tooth mobility. Int J Oral Maxillofac Implants 1988; 3:281–286.
28. Richter EJ, Spiekermann H, Jovanovic SA. Tooth-to-implant fixed prostheses: biomechanics based on in vitro and in vivo measurements. In: Laney WR, Tolman DE, eds. Tissue integration in oral, orthopaedic and maxillofacial reconstruction. Chicago, IL: Quintessence Publishing Co., 1990: 133–139.
29. Kay HB. Free-standing versus imlant-tooth-interconnected restorations: understanding the prosthodontic perspective. Int J Periodontics Restorative Dent 1993; 13:47–69.
30. Sullivan DY. Prosthetic considerations for the utilization of osseointegrated fixtures in the partially edentulous arch. Int J Oral Maxillofac Implants 1986; 1:39–45.
31. Ericsson I, Lekholm U, Bränemark PI, Lindhe J, Glantz PO, Nyman S. A clinical evaluation of fixed-bridge restorations supported by the combination of teeth and osseointegrated titanium implants. J Clin Periodontol 1986; 13:307–312.
32. Gunne J, Astrand P, Ahlen K, Borg K, Olsson M. Implants in partially edentulous patients. A longitudinal study of bridges supported by both implants and natural teeth. Clin Oral Implants Res 1992; 3:49–56.
33. Ericsson I, Glantz P-O, Bränemark P-I. Use of implants in restorative therapy in patients with reduced periodontal tissue support. Quintessence Int 1988; 19:801–807.
34. Lin CL, Wang JC. Nonlinear finite element analysis of a splinted implant with various connectors and occlusal forces. Int J Oral Maxillofac Implants 2003; 18:331–340.
35. Misch CM, Ismail YH. Finite element stress analysis of tooth-to-implant fixed partial denture designs. J Prosthodont 1993; 2:83–92.
36. Nishimura RD, Ochiai KT, Caputo AA, Jeong CM. Photoelastic stress analysis of load transfer to implants and natural teeth comparing rigid and semirigid connectors. J Prosthet Dent 1999; 81:696–703.
37. Breeding LC, Dixon DL, Sadler JP, McKay ML. Mechanical considerations for the implant tooth-supported fixed partial denture. J Prosthet Dent 1995; 74:487–492.
38. Lindh T, Dahlgren S, Gunnarsson K, et al. Tooth-implant supported fixed prostheses: a retrospective multicenter study. Int J Prosthodont 2001; 14:321–328.
39. Hosny M, Duyck J, van Steenberghe D, Naert I. Within-subject comparison between connected and nonconnected

tooth-to-implant fixed partial prostheses: up to 14-year follow-up study. Int J Prosthodont 2000; 13:340–346.
40. Pesun IJ. Intrusion of teeth in the combination implant-to-natural-tooth fixed partial denture: a review of the theories. J Prosthodont 1997; 6:268–277.
41. Rieder CE, Perel SM. A survey of natural tooth abutment intrusion with implant-connected fixed partial dentures. Int J Periodontics Restorative Dent 1993; 13:335–347.
42. Garcia LT, Oesterle LJ. Natural tooth intrusion phenomenon with implants: a survey. Int J Oral Maxillofac Implants 1998; 13:227–231.
43. Schlumberger TL, Bowley JF, Maze GI. Intrusion phenomenon in combination tooth-implant restorations: a review of the literature. J Prosthet Dent 1998; 80:199–203.
44. English CE. Root intrusion in tooth-implant combination cases. Implant Dent 1993; 2:79–85.
45. Sheets CG, Earthmann JC. Natural tooth intrusion and reversal in implant-assisted prosthesis: evidence of and a hypothesis for the occurrence. J Prosthet Dent 1993; 70:513–520.
46. Chiba M, Komatsu K. Mechanical responses of the periodontal ligament in the transverse section of the rat mandibular incisor at various velocities of loading in vitro. J Biomech 1993; 26:561–570.
47. Edwards JG. A study of the periodontium during orthodontic rotation of teeth. Am J Orthod 1979; 54:441–461.
48. McDowell JA, Regli CP. A quantitative analysis of the decrease in width of the mandibular arch during forced movements of the mandible. J Dent Res 1961; 40:1183–1185.
49. Regli CP, Kelly EK. The phenomenon of decreased mandibular arch width in opening movements. J Prosthet Dent 1967; 17:49–53.
50. Burch JG. Patterns of change in human mandibular arch width during jaw excursions. Arch Oral Biol 1972; 17:623–631.
51. Gates GN, Nicholls JI. Evaluation of mandibular arch width change. J Prosthet Dent 1981; 46:385–392.
52. Cordaro L, Ercoli C, Rossini C, Torsello F, Feng C. Retrospective evaluation of complete-arch fixed partial dentures connecting teeth and implant abutments in patients with normal and reduced periodontal support. J Prosthet Dent 2005; 94:313–320.
53. Ormianer Z, Brosh T, Laufer BZ, Shifman A. Strains recorded in a combined tooth-implant restoration: an in vivo study. Implant Dent 2005; 14:58–62.
54. Rieder CE. Copings on tooth and implant abutments for superstructure prostheses. Int J Periodontics Restorative Dent 1990; 10:436–453.
55. Cho GC, Chee WW. Apparent intrusion of natural teeth under an implant-supported prosthesis: a clinical report. J Prosthet Dent 1992; 68:3–5.
56. Cohn SA. Disuse atrophy of the periodontium in mice. Arch Oral Biol 1965; 10:909–919.
57. Cohn SA. Disuse atrophy of the periodontium in mice following partial loss of function. Arch Oral Biol 1966; 11:95–105.
58. Sheets CG, Earthman JC. Tooth intrusion in implant-assisted prostheses. J Prosthet Dent 1997 Jan; 77:39–45. Review. Erratum in: J Prosthet Dent 1997 Apr; 77(4):453.
59. Kronström M, Trulsson M, Soderfeldt B. Patient evaluation of treatment with fixed prostheses supported by implants or a combination of teeth and implants. J Prosthodont 2004; 13:160–165.
60. Kayacan R, Ballarini R, Mullen RL. Theoretical study of the effects of tooth and implant mobility differences on occlusal force transmission in tooth/implant-supported partial prostheses. J Prosthet Dent 1997; 78:391–399.
61. Zhiyong L, Arataki T, Shimamura I, Kishi M. The influence of prosthesis designs and loading conditions on the stress distribution of tooth-implant supported prostheses. Bull Tokyo Dent Coll 2004; 45:213–221.
62. Akca K, Uysal S, Cehreli MC. Implant–tooth-supported fixed partial prostheses: correlations between in vivo occlusal bite forces and marginal bone reactions. Clin Oral Implants Res 2006; 17:331–336.
63. Tangerud T, Gronningsaeter AG, Taylor A. Fixed partial dentures supported by natural teeth and Branemark system implants: a 3-year report. Int J Oral Maxillofac Implants 2002; 17:212–219.
64. Palmer RM, Howe LC, Palmer PJ. A prospective 3-year study of fixed bridges linking Astra Tech ST implants to natural teeth. Clin Oral Implants Res 2005; 16:302–307.
65. Lindh T, Back T, Nystrom E, Gunne J. Implant versus tooth-implant supported prostheses in the posterior maxilla: a 2-year report. Clin Oral Implants Res 2001; 12:441–449.
66. Astrand P, Borg K, Gunne J, Olsson M. Combination of natural teeth and osseointegrated implants as prosthesis abutments: a 2-year longitudinal study. Int J Oral Maxillofac Implants 1991; 6:305–312.
67. Olsson M, Gunne J, Astrand P, Borg K. Bridges supported by free-standing implants versus bridges supported by tooth and implant. A five-year prospective study. Clin Oral Implants Res 1995; 6:114–121.
68. Gunne J, Astrand P, Lindh T, Borg K, Olsson M. Tooth-implant and implant supported fixed partial dentures: a 10-year report. Int J Prosthodont 1999; 12:216–221.
69. Kindberg H, Gunne J, Kronström M. Tooth- and implant-supported prostheses: a retrospective clinical follow-up up to 8 years. Int J Prosthodont 2001; 14:575–581.
70. Block MS, Lirette D, Gardiner D, et al. Prospective evaluation of implants connected to teeth. Int J Oral Maxillofac Implants 2002; 17:473–487.
71. Naert IE, Duyck JA, Hosny MM, Quirynen M, van Steenberghe D. Freestanding and tooth-implant connected prostheses in the treatment of partially edentulous patients Part

II: an up to 15-years radiographic evaluation. Clin Oral Implants Res 2001; 12:245–251.

72. Laufer BZ, Gross M. Splinting osseointegrated implants and natural teeth in rehabilitation of partially edentulous patients. Part II: principles and applications. J Oral Rehabil 1998; 25:69–80.
73. Balshi TJ. Osseointegration for the periodontally compromised patient. Int J Prosthodont 1988; 1:51–58.
74. Naert IE, Duyck JA, Hosny MM, Van Steenberghe D. Freestanding and tooth-implant connected prostheses in the treatment of partially edentulous patients. Part I: an up to 15-years clinical evaluation. Clin Oral Implants Res 2001; 12:237–244.
75. Weinberg LA, Kruger B. Biomechanical considerations when combining tooth-supported and implant-supported prostheses. Oral Surg Oral Med Oral Pathol 1994; 78:22–27.
76. Rangert B, Gunne J, Sullivan DY. Mechanical aspects of a Branemark implant connected to a natural tooth: an in vitro study. Int J Oral Maxillofac Implants 1991; 6:177–186.
77. Ochiai KT, Ozawa S, Caputo AA, Nishimura RD. Photoelastic stress analysis of implant-tooth connected prostheses with segmented and nonsegmented abutments. J Prosthet Dent 2003; 89:495–502.
78. Pesun IJ, Steflik DE, Parr GR, Hanes PJ. Histologic evaluation of the periodontium of abutment teeth in combination implant/tooth fixed partial denture. Int J Oral Maxillofac Implants 1999; 14:342–350.
79. Pjetursson BE, Tan K, Lang NP, Bragger U, Egger M, Zwahlen M. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years. I. Implant-supported FPDs. Clin Oral Implants Res 2004 Dec; 15:625–642. Review.
80. Lang NP, Pjetursson BE, Tan K, Bragger U, Egger M, Zwahlen M. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years. II. Combined tooth – implant-supported FPDs. Clin Oral Implants Res 2004 Dec; 15:643–653. Review.
81. Bragger U, Karoussis I, Persson R, Pjetursson B, Salvi G, Lang N. Technical and biological complications/failures with single crowns and fixed partial dentures on implants: a 10-year prospective cohort study. Clin Oral Implants Res 2005; 16:326–334.
82. Velásquez-Plata D, Lutonsky J, Oshida Y, Jones R. A close-up look at an implant fracture: a case report. Int J Periodontics Restorative Dent 2002; 22:483–491.
83. Morgan MJ, James DF, Pilliar RM. Fractures of the fixture component of an osseointegrated implant. Int J Oral Maxillofac Implants 1993; 8:409–414.
84. Bragger U, Aeschlimann S, Burgin W, Hammerle CH, Lang NP. Biological and technical complications and failures with fixed partial dentures (FPD) on implants and teeth after four to five years of function. Clin Oral Implants Res 2001; 12:26–34.
85. Cohen SR, Orenstein JH. The use of attachments in combination implant and natural-tooth fixed partial dentures: a technical report. Int J Oral Maxillofac Implants 1994; 9:230–234.
86. Weyant RJ, Burt BA. An assessment of survival rates and within-patient clustering of failures for endosseous oral implants. J Dent Res 1993; 72:2–8.
87. Gross M, Laufer BZ. Splinting osseointegrated implants and natural teeth in rehabilitation of partially edentulous patients. Part I: laboratory and clinical studies. J Oral Rehabil 1997; 24:863–870.