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Hierarchical decisions on teeth vs. implants in the periodontitis-susceptible patient: the modern dilemma

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Osseointegrated implants were originally introduced for the treatment of fully edentulous jaws (25). Now, dental implants are frequently used to restore partially edentulous jaws. Dental implants are also increasingly being used as a means of tooth replacement in the management of patients with periodontal disease to replace teeth lost as a result of periodontitis.

The extraction of a periodontally compromised tooth and its subsequent replacement with a dental implant, as opposed to its retention by means of comprehensive periodontal therapy, is one of the most complex and debatable decisions that a dentist must make during everyday clinical practice. Usually, the decision to extract a tooth is based on multiple patient and site risk factors, determined according to periodontal, endodontic and restorative criteria, which are also associated with the strategic role of the tooth in the dentition. The choice of treatment may not be influenced solely by the scientific evidence on the efficacy of these two treatment principles (i.e. to maintain and treat the tooth or to extract the tooth and replace it with an implant). The dentist's personal clinical experience, access to technology and postgraduate education, as well as patient preferences and economic parameters, will also affect the decision-making process (77, 156, 157).

Current clinical evidence has positioned implants as one of the first choices of treatment for partially or fully edentulous patients and has influenced the decision to extract periodontitis-affected teeth, which in a number of cases may be treatable (27, 52, 108). It has been suggested that 'pro-active' or 'strategic extractions' will prevent further bone destruction in a potential implant site (78). However, such an approach is not always supported by the current evidence (50), especially if we consider that any tooth extraction will result in resorption of alveolar bone that cannot be completely controlled by either alveolar ridge-preservation techniques (110) or immediate implant placement (9, 20).

The concept of early extraction of periodontally involved teeth and their replacement with dental implants is based on a perceived advantage of implants over teeth in terms of: (i) unpredictability of tooth survival following treatment of periodontal disease, (ii) better long-term prognosis of implant-supported restorations in comparison to teeth or tooth-supported restorations, (iii) lack of complications in comparison with teeth, (iv) better function than teeth, (v) better long-term cost–benefit, (vi) better esthetics, and (vii) better patient satisfaction. However, it is questionable to which extent these postulations are supported by the current evidence.

It is also important to emphasize that the extraction of periodontitis-affected teeth does not resolve or eliminate the underlying host response-related problems that may have contributed to the development of periodontal disease and which may be predisposing factors for the development of peri-implantitis. Therefore, it could be argued that periodontally compromised teeth should be treated for as long as possible, being extracted and replaced by some means only when successful periodontal treatment is no longer possible. Admittedly, the 'good' or 'poor' prognosis of periodontally involved teeth is not always easy to predict.

Unfortunately, it seems that traditional well-documented and evidence-based means to treat

periodontal diseases are slowly being forgotten or are not always used to their full potential (108). Based on data from the early implant-survival studies, there is a widespread notion within the dental profession and the public that dental implants have a higher predictability for success and tend to have fewer complications than periodontally compromised but treated teeth. In a sense, a 'dogma' has been created that 'implants can solve all problems' (27). The direct comparison of teeth vs. implants is difficult to make because implants should be considered as a treatment for tooth loss and not as a tooth substitute. Before implant dentistry was available, significantly more effort was placed on preserving teeth. Today, when a tooth has a 'hopeless' or even a 'questionable' prognosis, the first treatment alternative is extraction and replacement with a dental implant. Therefore, it seems justified to revisit the concept of periodontitis management and to re-evaluate the inclusion criteria of periodontal patients qualifying for dental implants.

Q: Is treatment of periodontal disease predictable and will it lead to the survival of periodontally involved teeth?

Whereas some forms of periodontal disease may affect 40–50% of the adult population with increasing prevalence with increasing age, it has been suggested that advanced periodontal disease has an overall prevalence of approximately 10% in some developed countries (64). Individuals with advanced periodontal disease can be considered as highly susceptible to periodontitis and often present difficulties in therapeutic decision making. Poor plaque control and smoking are well-established risk factors for periodontitis development – as for peri-implant diseases (26, 56) – and also for disease progression following treatment (114, 115). Long-term follow-up studies have clearly demonstrated that treatment of periodontal disease (which may include extraction of hopeless teeth), even in its advanced forms, can, to a certain extent, be successful in arresting disease progression and minimizing, or even preventing, tooth loss (Table 1), provided that the patient is enrolled in a high-quality maintenance care program after completion of active treatment (28, 69, 84, 148, 160) and refrains from smoking (70).

Longitudinal studies have shown that within the adult normal population there is a natural annual bone-height reduction of about 0.10 mm (62, 170).

Table 1. Long-term tooth loss during maintenance care in patients treated for advanced periodontal disease

Author	Type of study	Number of patients	Patient mean age at baseline (years)	Mean (range) years of follow-up	Mean (%) number of teeth lost	Prevalence of patients losing teeth (%)	Mean number of teeth lost among patients losing teeth
Tonetti et al. (2000) (160)	Retrospective	273	NG	5.5 (0.5–23)	1.0 (4.2)	41	2.4
Rosling et al. (2001) (148)	Prospective	109	45	12	1.9 (7.9)	64	2.9
König et al. (2002) (87)	Retrospective	142	46	10	0.7 (3.2)	36	1.9
Fardal et al. (2004) (40)	Retrospective	100	46	9.8 (9–11)	0.4 (1.5)	21	1.7
Carnevale et al. (2007) (28)	Retrospective	304	52	7.8 (3–17)	0.2 (0.9)	16	1.3
Jansson & Lagervall (2008) (69)	Retrospective	60	41	16.2 (10–24)	2.3 (10.4)	NG	NG

NG, not given.

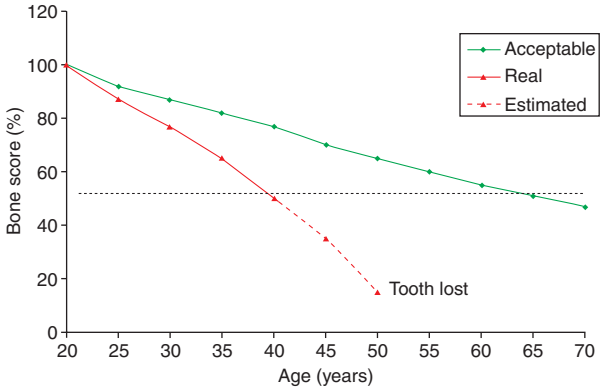

Fig. 1. Acceptable bone-height reduction and a real bone-height level of a 40-year-old patient suffering from periodontal disease, which would lead to further bone-height reduction and eventual tooth loss in the absence of adequate periodontal treatment (from Wennstrom et al. [168]).

Therefore, it would be reasonable to suggest that with adequate oral hygiene, regular dental check-ups and preventive care, any patient should have a bone score of at least 50% at 70 years of age, which is more than sufficient as support. Thus, it would be possible to extrapolate the periodontal development for any patient from (repeated) radiographs along a linear graph (Fig. 1) (169). Any patient whose bone score deviates from the acceptable at any age constitutes a patient at risk of further bone loss, or even of tooth loss, at an early age unless adequate periodontal treatment is provided.

This reasoning is exemplified by the case presented in Fig. 2. The patient is a 34-year-old nonsmoking woman diagnosed with advanced generalized aggressive periodontitis. In the maxilla she has lost about 60% of her bone support around all teeth. Yet, there is no clinically measurable increase in tooth mobility. She is at risk of losing her upper teeth at 40 years of age unless the disease progression can be arrested. Most teeth in the maxilla have a questionable prognosis, whereas the prognosis of the mandibular teeth is fair. Two treatment options are possible (Fig. 3A). The first would be to keep all (or most) teeth through successful periodontal treatment, followed by a stringent maintenance program. The second would comprise periodontal treatment, extraction of most or all teeth in the maxilla and replacement with a conventional removable partial or full denture, or with an implant-supported reconstruction and continuous infection control to prevent the development of peri-implantitis. As only a few teeth have a better periodontal status and prognosis than the others, extraction of some teeth and replacement with a cross-arch tooth-supported reconstruction would hardly be an option.

Figure 3B shows the patient 10 years after basic nonsurgical periodontal therapy, which included extraction of all second molars and tooth number 21, followed by open-flap debridement in the posterior regions of the maxilla and an anterior three-unit inlay bridge. The patient was then enrolled in, and complied

Fig. 2. Clinical and radiographic images of a 34-year-old woman diagnosed with advanced generalized aggressive periodontitis.

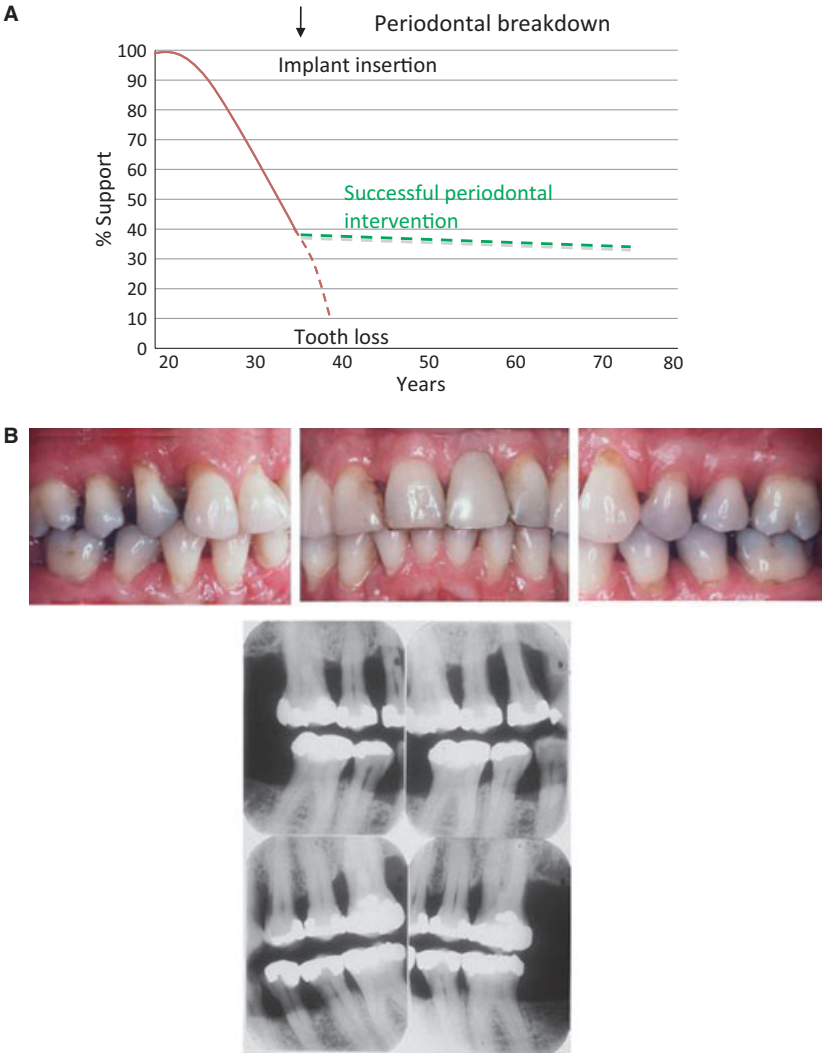

Fig. 3. (A) Bone-loss development and treatment options of the 34-year-old woman in Fig. 2 with advanced generalized aggressive periodontitis. (B) Clinical and radiographic illustration of the patient 10 years after completion of active treatment. Note the well-defined interproximal cortical bone walls indicating no disease activity.

with, a high-quality supportive periodontal treatment program for infection control, including periodontal examination every year, oral hygiene reinforcement and supra/subgingival scaling, as needed, every 3 months for the first 3 years postoperatively and every 6 months thereafter. This treatment outcome must be considered very successful and constitutes a valid treatment alternative to extractions and implant treatment. Positive prognostic factors were: no initial tooth mobility, no smoking, high motivation and very good self-performed plaque control, as demonstrated during initial therapy.

This case illustrates that even those dentitions with advanced periodontal breakdown can be successfully treated by conventional periodontal therapy and further breakdown may be prevented. It should be emphasized that even a moderately successful periodontal treatment may postpone extraction and implant treatment for several years, which, in turn, increases the possibility of such treatment lasting throughout the patient's lifetime (108).

Q: Prosthetic rehabilitation of the periodontally compromised patient: tooth-supported or implant-supported reconstructions?

Management of patients with advanced periodontal disease may include extraction and replacement of teeth with a hopeless prognosis. In such patients, basically three options are available for the rehabilitation: tooth-supported fixed partial dentures; implant-supported fixed partial dentures; or removable partial dentures (8). However, all teeth do not have to be replaced. The concept of the 'shortened dental arch' was recently evaluated in a systematic review (76). The included studies showed that shortened dental arches comprising anterior and premolar teeth in general fulfill the requirements of a functional dentition; therefore, the shortened dental-arch concept deserves serious consideration in treatment planning for par-

tially edentulous patients. However, with ongoing change, for example, in dental health and economy, the concept requires continuing research, evaluation and discussion (51). Patients' needs and demands vary considerably and should be individually assessed (149, 172), but the shortened dental-arch concept deserves to be included in all treatment-planning considerations for partially edentulous patients.

In the early 1970s an alternative concept of bridgework for prosthetic rehabilitation of dentitions with markedly reduced periodontal support was presented (107, 126). This 'periodontal–prosthodontic concept', which contradicted the generally accepted principles for bridgework (7), implied that 'fixed bridges can be placed and successfully maintained on a minimal number of abutment teeth with significantly reduced periodontal support provided the prosthodontic treatment is (i) preceded by adequate periodontal treatment and (ii) followed by a plaque control program effective enough to prevent recurrence of periodontitis'. In fact, if the bridgework is well distributed and periodontal disease is under control, as little as 10–20% of the original amount of periodontal support can be sufficient to carry cross-arch bridges (94). Long-term follow-up studies on combined periodontal and fixed partial-denture treatment of patients with advanced periodontal breakdown have confirmed this hypothesis (102). From the data of six long-term follow-up studies that analyzed a total of 579 cross-arch bridges, it has been concluded that the estimated 10-year survival and success rates were above 90% (102). These rates are higher than those identified for implant-supported and conventional fixed partial dentures (138). In a recent retrospective study (44), 80 patients treated for periodontitis and subsequently provided with 94 cross-arch stabilizing bridges and complying with a stringent maintenance periodontal care program were followed for an average of 10 years. The survival rate of these bridges was 98%, and there were few technical and biological complications.

The periodontal-prosthodontic concept is illustrated in Fig. 4. The patient is a 46-year-old man diagnosed with advanced generalized chronic periodontitis. Several teeth in the maxilla (i.e. teeth 16, 12, 11, 21 and 22) have a hopeless periodontal prognosis. Teeth 15, 13 and 23 may be considered to have a questionable prognosis as they have lost at least one-third of their bone support and present with slightly increased mobility. Only teeth 17 and 25 are periodontally secure. The overall prognosis of the teeth in the maxilla is questionable, whereas the periodontal prognosis for the teeth in the mandible is

Fig. 4. Clinical and radiographic images of a 46-year-old man diagnosed with advanced generalized chronic periodontitis.

secure. Two treatment options, both preceded by basic periodontal therapy, are possible: (i) extraction of all teeth in the maxilla followed by an immediate provisional complete denture and eventually an implant-supported reconstruction, or (ii) extraction of the hopeless teeth, provision of a temporary acrylic bridge, pocket elimination surgery of the questionable teeth and, finally, after a 6- to 12-month re-evaluation and positive outcome, a cross-arch tooth-supported fixed partial denture. A removable partial denture is not a good option because of the increased mobility of the questionable teeth. When choosing between a conservative treatment plan (maintaining teeth as abutments for a fixed bridge) or a treatment plan with implant-supported reconstructions, it should be borne in mind that patients who have lost teeth as a result of periodontal disease are also at risk of developing peri-implantitis (56, 128).

The treatment provided followed the conservative approach outlined in the previous paragraph and was completed with a 12-unit bridge from teeth 17–25 supported on teeth 17, 15, 13, 23 and 25. The ratio of remaining periodontal ligament support compared with bridge extension was 22% (93) (Fig. 5), which can be sufficient if the abutments are favorably distributed. The patient was then enrolled in a periodontal supportive therapy program, including examination and control of the bridge and occlusion annually, together with twice-yearly oral hygiene reinforcement and subgingival scaling and polishing as needed.

Fig. 5. Temporary acrylic bridge (left), the permanent metal-ceramic bridge (right) and radiographs after 5 years of follow-up.

Technical complications

Technical complications that may occur in tooth-supported fixed partial dentures are loss of retention of abutment crowns and fracture of abutment teeth and/or bridge (138). In periodontal-prosthodontic fixed partial dentures, the long clinical crowns enable tooth preparations that will secure the retention of the construction. Likewise, the previous periodontal breakdown will allow for proper dimensioning of the metal framework, preventing fracture of the construction (94). As a consequence, the incidence of technical problems, including loss of retention, seems to be much lower for these types of bridges than for 'conventional bridges'. Biological complications in such patients are evidently few and mainly of caries or endodontic character, whereas periodontal complications in patients enrolled in maintenance programs are infrequent (44, 102).

Conclusion

Comparable survival and success rates can be anticipated following prosthetic restoration with either tooth-supported or implant-supported fixed partial dentures.

Q: What is the functional capacity of tooth-supported vs. implant-supported cross-arch fixed partial dentures?

At the time of the introduction of osseointegrated implants to restore the edentulous jaw, a number of investigations were performed to assess the functional capacity of such reconstructions. Usually the lower jaw was provided with a 10- to 12-unit implant-supported fixed partial denture occluding with an upper complete denture. Muscular function during chewing and swallowing, expressed as jaw-closing muscular activity, was assessed by electromyography, number of chewing strokes and chewing rate, and bite force was measured with a bite fork inserted between the jaws. It was concluded that patients with osseointegrated implant-supported fixed prostheses had a masticatory muscle function equal to or approaching that of patients with natural teeth or tooth-supported bridges of the same extension (54, 55).

A more detailed analysis of the occlusal force pattern of periodontally treated and prosthetically restored dentitions was made possible by the introduction of new methods based on miniature strain transducers built into artificial crowns, bridge pontics or removable dentures without interfering with the occlusion (103). Using this method, naturally occurring occlusal chewing and swallowing forces, as well as occlusal loads developed during maximal biting in habitual occlusion, could be measured in various parts of the dentition as well as over the entire dentition simultaneously. In addition, chewing cycle duration, and number and duration of chewing strokes during a chewing sequence could be assessed.

This method was then applied in a series of studies to analyse occlusal force patterns in various designs of tooth-supported (93, 104, 105) and implant-supported (38, 106) fixed cross-arch bridges. Registrations of a chewing sequence in a patient with a tooth-supported and an implant-supported cross-arch fixed partial denture are shown in Fig. 6. These two registration graphs clearly demonstrate the similarity in chewing patterns, including chewing force magnitude and duration, between patients with tooth-supported or implant-supported reconstructions.

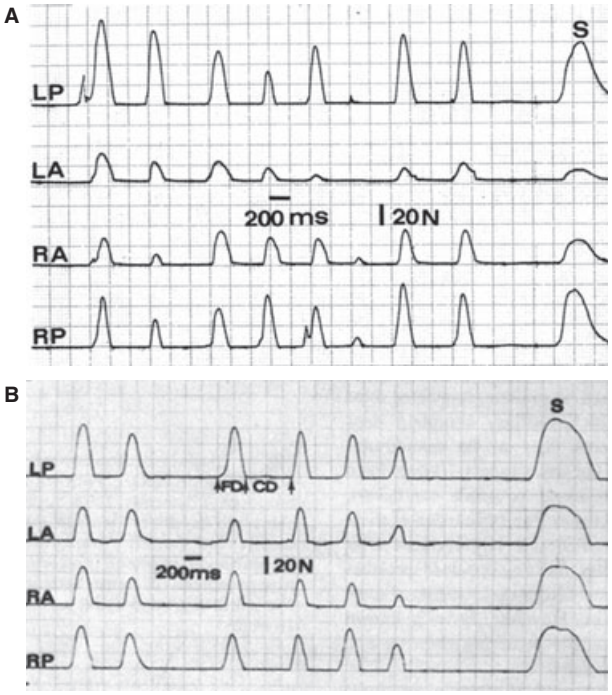

Fig. 6. (A) Registrations of a chewing sequence followed by swallowing (S) in a periodontally treated patient supplied with a maxillary cross-arch tooth-supported bilateral end-abutment bridge occluding with natural teeth. Four strain-gauge transducers representing the left posterior (LP), left anterior (LA), right anterior (RA) and right posterior (RP) areas were used. (B) Registrations of a chewing sequence followed by swallowing (S) in a patient supplied with a mandibular cross-arch implant-supported bridge occluding with a complete denture. Four strain-gauge transducers representing the left posterior (LP), left anterior (LA), right anterior (RA) and right posterior (RP) areas were used. CD, chewing cycle duration from the start of one chewing stroke to the start of the next; FD, occlusal force duration.

Table 2 depicts data on maximal bite force, chewing force, chewing cycle duration and chewing force duration for tooth-supported and implant-supported cross-arch fixed dental prostheses (38, 104, 105). The tooth-supported reconstructions were all supported on a few abutment teeth with markedly reduced periodontal support. Clearly there were no differences in these variables between tooth-supported and implant-supported reconstructions. In addition, the chewing ability of patients periodontally treated and restored with cross-arch bridges was as efficient as that of individuals with complete healthy dentitions and superior to that of complete denture wearers.

Conclusion

Cross-arch bridges on significantly reduced periodontal support and implant-supported reconstructions seem to function equally well.

Q: Do dental implants present with better prognosis and fewer complications than periodontally compromised but treated teeth?

The issue of defining and correlating the prognosis of periodontally involved teeth during the different stages of periodontal therapy with the successful outcome of long-standing survival as a healthy unit is an enduring debate within periodontology (116, 117). Even more so, the current comparison of outcomes for teeth treated for periodontal disease vs. dental implants, which very often have been placed in healthy dentitions not previously affected by periodontal disease, is very challenging.

Implant survival means that the implant is still in place without considering biological and/or technical complications, function or clinical value. Survival rate is the proportion of implants still in place at a certain time (34). Survival rates exceeding 90% are commonly presented in retrospective follow-up studies on implant-supported reconstructions. However, 10-year prospective longitudinal studies on implant-supported fixed partial dentures are few as

Table 2. Mean maximal bite force and mean chewing force (both expressed in Newtons), and mean chewing cycle and mean chewing force duration (both expressed in msec) for patients with various prosthetic reconstructions during chewing of peanuts

Type of bridge construction	Mean maximal bite force	Mean total chewing force	Chewing cycle duration	Chewing force duration
Tooth-supported bilateral end abutments (n = 12)	320 ± 117	109 ± 64	636 ± 102	238 ± 34
Tooth-supported unilateral two-unit cantilevers (n = 12)	264 ± 108	55 ± 19	550 ± 85	191 ± 95
Tooth-supported bilateral two-unit cantilevers (n = 6)	309 ± 90	121 ± 71	622 ± 81	231 ± 37
Implant-supported bilateral two-unit cantilevers (n = 10)	254 ± 92	134 ± 49	645 ± 175	256 ± 58

are the number of patients included in those studies (158). Nevertheless, a number of recent stringent systematic reviews (73, 90, 138–141) have addressed the survival rates of the different restorative treatment solutions: single crown, implant–implant reconstruction and implant–tooth reconstruction. The 10-year estimated survival rates were 96.3%, 92.8% and 82.1% for single-implant crowns, implant–implant reconstructions and implant–tooth reconstructions, respectively. These results compare favorably with the survival rates of standard tooth-supported fixed dental prostheses and extensive tooth-supported fixed partial dentures in periodontally compromised patients (94, 102).

Complications

Implant success means that the reconstruction is free from all complications and has not required any intervention during the observation period. Biological as well as technical complications may occur.

Biological complications

Biological complications include peri-implant diseases (96). Peri-implant mucositis is described as 'the presence of inflammation in the mucosa surrounding an implant with no signs of loss of supporting bone', whereas peri-implantitis (Figs 7 and 8) is described as 'in addition to the inflammation of the mucosa, loss of supporting bone is also present' (175).

Although peri-implantitis is gradually being recognized as a disease entity that constitutes a therapeutic dilemma, data on the prevalence of peri-implant diseases are still scarce. In a previous systematic review, Berglundh et al. (18) discussed the difficulty of retrieving information on the prevalence of peri-implantitis owing to the fact that the definition of the disease (1) was included in very few studies. In a more recent systematic review (175), the prevalence of peri-implant diseases was presented based on cross-sectional and longitudinal studies, with more than 50 patients included at study termination and with implants having functioned for at least for 5 years. Peri-implant mucositis was present in approximately 80% of the subjects and at 50% of the implant sites. The prevalence of peri-implantitis varied between 28% and 56% of the subjects and between 12% and 43% of the implants (96, 175). A history of periodontal disease, smoking and poor oral hygiene were identified as risk indicators for developing peri-implantitis (26, 56, 57, 80, 81, 112, 128).

Technical complications

Despite high survival rates, implant-supported reconstructions seem to present with more technical complications than tooth-supported reconstructions. Thus, in a recent systematic review, the incidence of technical complications for implant-supported reconstructions was 39% compared with 16% for tooth-supported reconstructions (138).

Conclusion

Teeth may last for a long time. Even periodontally compromised but treated teeth in well-maintained patients have survival rates of ≥90%. The 10-year survival rate of implants varies between 82% and 94% (60). Furthermore, survival data on implants primarily relate to implant systems that are no longer available. The notion that implants survive for longer than teeth, as sometimes suggested by implant companies, has no scientific support.

Q: Is treatment of peri-implantitis predictable?

There is currently no long-term evidence that peri-implantitis can be treated in a predictable manner. Peri-implantitis constitutes an increasing clinical problem, which, in contrast to (recurrent) periodontal disease, does not seem to be treatable by nonsurgical means (145, 146). Different surgical techniques, from resective surgery with apically repositioned flaps to guided bone regeneration with or without bone grafts and surface decontamination, have been evaluated and showed varying degrees of success (30). We are currently not in a position to provide solid advice to dental surgeons regarding a long-term predictable treatment of peri-implantitis. Owing to the aggressive nature of the disease (175, 176) and the fact that an ideal method of implant surface decontamination has yet to be demonstrated, it could be suggested that peri-implantitis can currently be arrested only by resective surgery (147). Even though such a procedure will cause significant esthetic impairment at the implant site, proper oral hygiene procedures and control of disease progression at the site are facilitated.

It has recently been suggested that the pattern of peri-implantitis-associated bone loss may vary between subjects but is generally characterized by a nonlinear progression with increasing rate of bone loss over time (45). This implies that a case of peri-

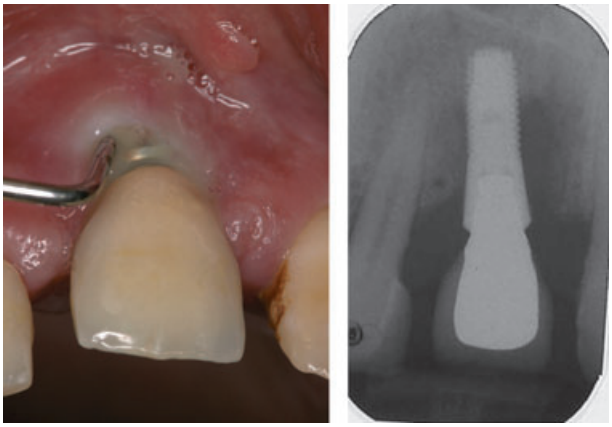

Fig. 7. Clinical and radiographic image of a peri-implantitis lesion characterized by deep probing depth, suppuration and a radiographic peri-implant osseous defect.

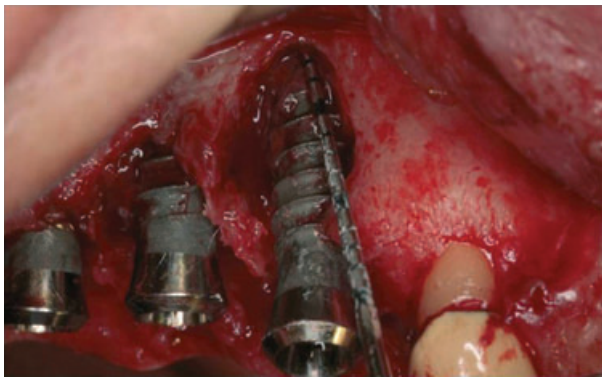

Fig. 8. Significant bone loss around implants as a result of peri-implantitis, rendering the prognosis of the implants as poor.

implantitis should be treated without delay and that surgical intervention is required earlier and more frequently than in a case of periodontitis (58). Similarly to the concept of 'proactive extraction' of the periodontally involved teeth, there are studies suggesting an 'early' explantation of the ailing implant as soon as its prognosis becomes hopeless in order to avoid further bone loss and to increase the potential for successful re-implantation (109, 111).

Q: Is there a risk for further disease progression and subsequent tooth loss after completion of periodontal treatment? Would dental implants 'resist' such a risk?

Chronic periodontitis is a common, slowly progressive disease in adults that is characterized by increasing probing pocket depths, attachment loss and alveolar bone loss (14, 19, 22, 63, 99, 126, 127, 133). Residual pockets after treatment may be predictive of further disease progression (31, 144) as a significant correlation seems to exist between attachment loss of ≥2.5 mm and patient-based proportions of sites with residual probing depth of ≥6 mm at 3 months following initial, cause-related therapy. Furthermore, residual periodontal pockets of ≥6 mm after several years of supportive periodontal therapy implies unsuccessful treatment outcome and further treatment needs, because, when combined with bleeding on probing scores of ≥30%, residual pockets constitute a risk for further tooth loss (114, 115).

Overall, both nonsurgical and surgical periodontal therapy will lead to a significant improvement in periodontal health. However, in the everyday clinical situation, all patients may not respond to treatment in a similar manner (40, 42, 43, 143). Therefore, a need for active retreatment as a result of the progression of periodontal disease may occur (74). In a recent study, half of the patients who were treated surgically and had received supportive periodontal therapy for 13 years required retreatment, including periodontal surgery (42). In most of these cases, retreatment seemed to control further tooth loss for patients presenting with a poor initial diagnosis, erratic compliance and a family history of periodontal disease; this suggested a need for continuous and dynamic observation of the periodontitis-susceptible patient. This is in line with the observation that within a given population of periodontal patients on periodontal supportive therapy there will be 'an increase in the prevalence of patients with high risk sites and an increase in the average number of sites with elevated risk for disease progression in a given subject' (159). Furthermore, patients with advanced periodontal disease are likely to present with more sites with increased probing depth and tooth loss than patients with moderate periodontal disease, indicating that previous disease experience offers a clinical estimation of the patient's susceptibility to periodontal disease (132, 133, 159). As such, patients have been previously classified as 'well maintained', 'downhill' or 'extreme downhill' according to tooth loss, thus expressing their disease-susceptibility level (59).

Susceptibility to periodontal disease and its consequences was also discussed in another study where 64% of the 'highly susceptible patients' experienced further tooth loss over a 12-year period of periodontal supportive therapy after active treatment while the

corresponding prevalence among 'normal/nonsusceptible' patients was 26% (148). This problem with the highly susceptible patient is very relevant to the scope of this paper because it poses serious questions on the survival of implants placed in patients belonging to this category. In a recent long-term follow-up study, a small number of treated periodontitis patients on maintenance care were found to be refractory to treatment and experienced further tooth loss (43). Furthermore, 25% of the implants placed in these periodontitis-susceptible patients were lost during the observation period, and 64% of the patients lost at least one implant. No implants were lost in the control group. Heavy smoking, stress and a family history of periodontal disease were the factors associated with refractory periodontitis and implant loss. The devastating effect that periodontal disease susceptibility might have on dental implants was also shown in an earlier case report by the same group (41).

A possible explanation for the impact that periodontal disease may have on dental implants may be the transmission of periodontal pathogens from periodontally compromised teeth to neighboring implants in partially edentulous periodontitis patients (124, 130, 131). It is important, however, to emphasize that even though the presence of putative periodontal pathogens at peri-implant sites is positively correlated to deeper peri-implant probing depths and clinical inflammation (75), the presence of the pathogens per se may not be considered as an absolute predictor of implant failure (150).

Conclusion

The progression of periodontal disease and the reinfection of sites, as well as further tooth loss, can occur, despite treatment, especially in patients who are highly susceptible to periodontitis. A history of periodontitis implies an increased risk of implant complications. Consequently, if implant treatment is considered in periodontitis-susceptible patients it should be preceded by adequate periodontal treatment, or even retreatment, to control the condition and should be followed by a stringent supportive infection-control program to prevent the development of peri-implant diseases. Identification of the patient's susceptibility profile must have an influence on the decision of whether implant treatment should be performed.

Q: Is periodontal supportive therapy in implant patients as effective as it is in periodontitis patients and what is the most effective maintenance/supportive-care regime for implants placed in a periodontitis-susceptible patient?

It is a well-established fact that supportive periodontal therapy is a prerequisite for maintaining acquired periodontal health and preventing disease recurrence and (further) tooth loss (12, 74, 97, 137, 144, 148). The importance of periodontal supportive therapy for the long-term survival of implants placed in treated periodontitis patients is also well documented (167). The procedures to be followed at regular intervals are similar to the usual periodontal supportive-therapy procedures for prevention of periodontitis and should include peri-implant probing pocket depth, peri-implant bleeding on probing and radiographic assessment of marginal bone loss (32, 66).

A systematic approach for the prevention and treatment of peri-implant diseases has been recommended in the Cumulative Interceptive Supportive Therapy protocol (88, 92). In a number of prospective cohort studies, the Cumulative Interceptive Supportive Therapy protocol has been shown to be effective in terms of improvement of clinical and microbiological parameters in peri-implantitis defects (122, 123, 136). Thus, it is important to inform the general dental surgeon providing the periodontal supportive therapy not only about the necessity, but also of the design, of relevant periodontal supportive-therapy regimens. Considering the number of publications on implant dentistry procedures, it is interesting to note that a recent systematic review, which assessed whether long-term supportive-treatment procedures prevented the development of peri-implant disease and implant loss, revealed that there is no evidence available to suggest the frequency of recall intervals or to propose specific hygiene regimes (65). However, to make effective supportive care possible, it is a prerequisite that the design of the implant-supported fixed partial denture is such that it permits access for plaque control performed by the patient and by the dentist and/or dental hygienist (151).

Conclusion

In patients previously treated for periodontal disease and restored with implant-supported fixed partial

dentures, supportive care has a positive effect on both tooth and implant survival. However, the design and frequency of a periodontal supportive therapy regime for implant patients has not yet been validated.

Suggestion for a supportive periodontal therapy / infection control program for patients restored with implant-supported reconstructions

The dentist must ensure that the patient receives supportive periodontal therapy that is effective enough to prevent the development or recurrence of infection around teeth and implants. Basically, the regimes of periodontal supportive therapy should be similar to those recommended for periodontitis patients. The following is suggested by the authors:

- Radiographic documentation immediately post-implant placement, at the delivery of the prosthetic construction and at the 1-year follow up to achieve baseline data for future follow up and to permit determination of the time of occurrence of any potential peri-implant bone loss.
- Following completion of the treatment, the patient is informed / instructed how to carry out self-performed plaque control, focusing on interdental cleaning with interproximal brushes. The patient should also be enrolled in an individually designed professional supportive-care program according to their specific risk-assessment profile.
- Clinical examinations every 3, 6 or 12 months should be performed depending on the severity of the case and the presence of risk factors for disease development / progression. Besides evaluating the function of the prosthesis, the examination should include evaluations of bleeding on probing, probing depths and presence of plaque.
- Professional plaque-control measures, including oral hygiene reinforcement and subgingival / mucosal instrumentation, should be performed, as indicated, every 3–6 months using ultrasonic and hand instruments specially modified for titanium surfaces.
- The presence of high bleeding on probing scores and probing pocket depth ≥5 mm are indications for further radiographic examination for bone margin evaluation and determination of treatment according to Cumulative Interceptive Supportive Therapy, as needed.

Q: Is it possible to create a clinical risk assessment as a guide in the decision on whether to replace periodontally compromised teeth with implants?

During treatment planning for the periodontitis patient, the primary goal should focus on maintaining the teeth through adequate periodontal therapy, thus postponing their replacement with dental implants (108). It is the suggestion of the authors of the present manuscript that when the above is no longer possible, the decision of whether or not to replace periodontally compromised teeth with dental implants should be based on two levels of risk assessment: the patient level and the site level. This risk assessment would provide guidelines on the potential risks of implant treatment in a certain patient. This suggestion is a modification of the risk-assessment program that was originally created for periodontitis-susceptible patients to predict periodontal disease recurrence and suggest maintenance care programs (91).

Suggested risk-assessment parameters

Patient level

At the patient level, the suggested risk-assessment parameters are: (i) bleeding on probing score, (ii) prevalence of residual pockets ≥5 mm, (iii) number of lost teeth, (iv) loss of attachment / bone level support in relation to patient's age, (v) systemic and genetic conditions, and (vi) environmental factors such as smoking. A patient can be classified as having a low-, moderate- or high-risk profile.

In practical terms, a low-risk-profile patient is one who has responded favorably to periodontal therapy and presents with optimal oral hygiene, does not smoke, is systemically healthy and runs a low risk for periodontal disease. In such a patient, the risk associated with replacement of lost / hopeless / questionable teeth with dental implants will be low (Fig. 9).

A patient with a moderate-risk profile has, for instance, a limited number of residual sites with probing pocket depth ≥5 mm that bleed upon probing following completion of periodontal therapy and the oral hygiene is not constantly optimal. Before any final restorative treatment plan with dental implants, an attempt for further pocket reduction should be considered. At this stage, the dentist should consider restorative treatment options other than dental

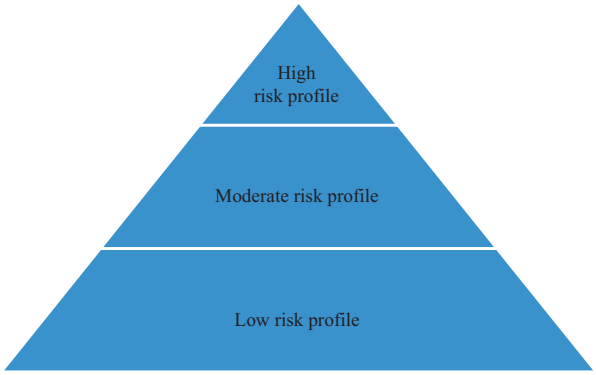

Fig. 9. The combined patient and site risk assessment could be described as a pyramid where the majority of patients would be allocated at a low or moderate risk profile for implant complications, with only a small percentage of subjects presenting high susceptibility to periodontitis and thereby a high-risk profile for implant complications. Possible scenarios for the different risk profiles can be described as follows: High-risk profile – *Patient level*: presence of aggressive or refractory periodontitis, high plaque and bleeding on probing scores and smoking. High esthetic demands and high treatment costs. *Site level*: compromised alveolar bone quality and quantity with need for hard and soft tissue augmentation, with neighboring teeth presenting with residual pockets ≥5 mm and bleeding on probing. *Suggestion*: restoration with implants should be avoided. Moderate-risk profile – *Patient level*: previous periodontal disease overall successfully treated but the patient still presents a limited number of residual pockets and the oral hygiene might not be always optimal. Patient prepared to accept compromised esthetic outcome and is able to afford a moderate / high-cost restorative solution. *Site level:* suboptimal local alveolar bone availability not requiring extensive augmentation procedures. Neighboring teeth might require periodontal retreatment. *Suggestion*: restoration with implants should be delayed until periodontal conditions are stable. Low-risk profile – *Patient level*: Systemically healthy, patient has responded very favorably to periodontal therapy with optimal oral hygiene, has low functional and esthetic demands with no cost-related concerns. *Site level:* adequate bone quantity, neighboring teeth periodontally and endodontically stable. *Suggestion*: restoration with implants is possible.

implants, such as interim tooth-supported reconstructions (Fig. 9).

A patient with a high-risk profile has a significant number of residual sites with probing pocket depths ≥5 mm that bleed upon probing, the oral hygiene is suboptimal and / or the patient is a heavy smoker and / or, for example, suffers from uncontrolled type 2 diabetes. In such a patient, implant placement should be delayed and further periodontal treatment must be provided as maintenance of teeth should be a priority. Furthermore, a relevant restorative treatment plan should be based on teeth rather than on implants. In a patient with a high-risk profile, the later the implants are installed, the further in the future implant failure might occur (108) (Fig. 9).

The suggested application of this risk-assessment program is based on (i) the assumption that the risk factors for periodontal disease and peri-implantitis are common (56, 58) and (ii) on data from studies indicating that patients who have been treated for periodontal disease present an increased rate of peri-implant complications (89, 112, 128, 152). For example, patients with aggressive periodontitis appear to have a lower implant-survival rate (3, 33, 118) and more bone loss around teeth and implants than chronic periodontitis patients after 3 and 10 years (118, 119, 120, 121). Even though further research is required, these observations place aggressive periodontitis patients in the high-risk-profile category for possible complications following dental implants. This knowledge emphasizes the importance of appropriate periodontal diagnosis during baseline examination.

Site level

Parameters to be addressed at the site level are presence of residual peri-apical lesions, height / width and quality of alveolar bone, soft tissue biotype, proximity to anatomic structures and condition of neighboring teeth. An evaluation of the condition of neighboring teeth (adapted from (89)) would include: (i) residual periodontal pockets, bleeding on probing and suppuration, (ii) tooth anatomy and positioning (i.e. root proximity, inclination, reduced restorative space), (iii) furcation involvement, (iv) presence of iatrogenic factors (i.e. overhanging margins of restoration or crowns), and (v) tooth mobility. An aggravating element would be teeth presenting with a combination of endodontic / restorative and periodontal problems.

A combined patient and site risk-assessment could facilitate not only the prognostication for further periodontal treatment but would also address the question of whether the replacement of periodontally compromised teeth with implant-supported restorations could be advocated.

Conclusion

The suggested two levels of risk assessment will define the level of risk for periodontal disease progression and possible complications following implant treatment. As this is a dynamic process, an extended observation period following the completion of periodontal therapy is strongly advocated to establish if teeth / sites will present with recurrent disease, in

particular next to intended implant areas. The extended observation period during which the moderate-risk and high-risk patient will be treated either with a temporary bridge in a tooth-supported restorative plan or with temporary resin-bonded bridges in the esthetic areas in an implant-based treatment plan will allow for retreatment of sites or extractions and relative modification of the final restorative treatment plan. It is important to emphasize that for high-risk-profile patients with multiple sites presenting recurrence of disease, a conservative restorative treatment approach is strongly recommended.

Q: Is there need for further training and clinical expertise on management of periodontitis-susceptible patients intended for implant treatment?

The worldwide dramatic increase in the demand for and offer of implant dentistry (71), both in terms of treatment and education (13, 35), is not associated with a corresponding decrease in the need for periodontal therapy (86). The increasing offer and acceptance of implant therapy for patients with periodontal disease will result in an increasing number of general dentists involved not only in the surgical/restorative part of implant dentistry, but even more importantly in the maintenance care of these patients. The following question then arises: is the general dentist sufficiently trained for this task?

Even though there is some limited evidence that trained general dental surgeons can achieve implant-survival rates similar to specialists (4), one could assume that a considerable amount of training and continuous education would be required in order to ensure that the overall clinical success with dental implants reported by specialist-related treatment centers will be maintained in the future by a much broader base of general dental practitioners (35, 165). Basic training courses of a few days' duration based on product information by implant companies will not be sufficient (35, 113). Training courses should also include selection of appropriate patients and preparing them for possible implant treatment. Although the clinician's experience may not be a major factor influencing survival or the optimal positioning of the implants (85, 164), it would be reasonable to assume that the level of expertise and clinical experience would influence not only the decision on whether to extract or treat and maintain periodontally involved teeth, but also the strategies for preventing complications related to implants. The classification of a tooth as 'hopeless', and its subsequent extraction at a relatively early stage of the disease process when minimal/moderate periodontal destruction has occurred, does not follow the existing evidence on the possibility to maintain periodontally involved teeth (82, 154).

The seemingly increased volume of medico-legal claims for both misdiagnosed and untreated periodontal disease, as well as inappropriate implant treatment, reflects the need for the acquisition of highly specialized diagnostic and treatment skills in implant dentistry. At the same time, this necessitates increased specialist competence for treating complications associated with dental implants (13, 35, 113, 175). In conclusion, further, postgraduate training is needed for any general dentist involved in implant treatment of periodontitis-susceptible patients in particular.

Q: Can the extraction of a periodontally compromised tooth and its replacement with a dental implant be justified from an economic point of view?

Implant-supported prostheses may be clinically effective but are more expensive than other prosthodontic alternatives (95, 153), the maintenance of periodontally involved teeth (142) or efforts to save endodontically compromised teeth (67). Therefore, their overall economic effectiveness has yet to be proven, considering that implants are economically inaccessible to a significant number of patients who would need them (156, 174). Currently, only a few private or public insurance dental plans cover such treatment (53). Acknowledging the fact that economic parameters drive the treatment chosen by both the patient and the dentist (36), and influence the patient's compliance (39, 171) as well as health-policy decision-makers, cost-effectiveness considerations, besides clinical evidence and patient's preferences, should also be part of the clinical decision-making process. A comprehensive economic analysis will address cost-effectiveness considerations by comparing the incremental costs and benefits of one treatment with any alternatives over a significant period of time (36). The benefits for the patient of receiving an implant-supported restoration to replace a periodontally

compromised tooth should exceed the costs of such an intervention and their ratio should be superior to that produced by periodontal treatment provided to maintain this tooth. The incremental cost of an implant-supported restoration should include (besides the direct and indirect costs of actual implant placement) all the costs arising before (e.g. tooth extraction, sinus lift, ridge preservation or ridge augmentation) and after (e.g. maintenance, treatment of possible biological or technical complications) the procedure, minus all the direct, indirect and induced costs (e.g. periodontal supportive therapy, treatment of hypersensitivity as a result of periodontal treatment) arising during and following comprehensive periodontal treatment (5, 6, 134). In a similar way, the incremental benefit for the patient following implant therapy should include all the benefits related to implant-supported prostheses (e.g. chewing function, esthetics) minus the benefits of preserving the tooth by means of periodontal therapy (e.g. a reduced but still satisfactory chewing function because of residual tooth mobility). In the specific topic, comparative economic analyses (cost-effectiveness analysis, cost–utility analysis and cost–benefit analysis) should establish the relative economic value of replacing periodontally compromised teeth with dental implants (2, 23, 36, 95). Cost–utility analysis theoretically has an advantage over the other two types of analyses as it allows comparison between procedures whose outcomes are different (e.g. clinical attachment / bone loss, tooth longevity vs. implant survival and success, peri-implant bone levels) or indeed a combination of several single outcomes. On the other hand, it is a challenging methodological task to provide universally accepted, preference-based outcome criteria (utility measurements) for both periodontal and implant treatments. Such utility measurements could be expressed in surrogate measurements similar to those previously suggested for caries (i.e. quality-adjusted tooth years) or for implant-supported prostheses (i.e. quality-adjusted prosthesis years) (68).

Currently, very few studies have associated clinical or patient-based outcomes with the resources (funds, personnel, equipment, facilities, etc.) used for either implant (161) or periodontal (23, 48) treatment. Economic evaluation data addressing our hierarchical dilemma are largely missing because there are no randomized controlled trials that directly compare the incremental cost–benefits / utilities of treatments aimed at periodontally compromised tooth retention with those using dental implants for their replacement. Recent reports have justified the higher cost for implant-supported prostheses in comparison with other fixed (21, 24) or removable alternatives as the benefits for patients who have undergone implant treatment are greater. On the other hand, the cost-effectiveness for preserving an endodontically involved tooth by means of root canal treatment was superior to its replacement with an implant-supported restoration, suggesting that implants may have a role only as a third line of intervention and only if and when endodontic retreatment fails (135).

Currently, there is some evidence supporting the superior cost-effectiveness of nonsurgical over surgical periodontal therapy to improve and stabilize periodontal conditions (5), whereas an economic advantage for the use of adjunctive genetic or microbiological tests, or local antibiotics, for managing periodontal disease could not be demonstrated (23, 48). Furthermore, there is a consensus for the importance of periodontal supportive therapy for the maintenance of periodontal health (89). The direct costs for periodontal tooth retention via periodontal supportive therapy have been found to be relatively low compared with prosthetic replacement with either implant-supported or tooth-supported fixed partial dentures (142). In addition, the outcome of periodontal supportive therapy was better when provided by specialists than by general practitioners, but came at a higher cost (46). The results of these studies however, should be interpreted with caution because a comparison of just the costs of a treatment intervention, without taking into consideration the resulting patient benefits, is not sufficient to support whether or not a specific treatment is economically more efficient than a treatment alternative (134).

From society's point of view, the available resources should be allocated in such a way to ensure that the best possible outcomes are achieved with the lowest possible cost. From the patient's and the public health perspective, the prevention of periodontal disease progression seems to be of greater economic importance in comparison to lengthy and expensive periodontal treatment to prevent or delay tooth loss, or expensive reconstructions on teeth or implants to restore missing teeth (79). Thus, the early identification of patients at increased risk for periodontal disease and the provision of preventive periodontal treatment may present the most economically efficient way for society to tackle the problem.

Conclusions

Considering the fact that only a relatively small proportion of the population is susceptible to severe

periodontal disease/tooth loss and that this population also presents a higher rate of implant complications, it would be reasonable to assume that the early prevention of periodontal disease is the best way to save not only financial resources but also teeth.

Q: Are patients more satisfied with tooth extraction and an implant than with periodontal treatment?

Patient satisfaction is a major issue in dental-care delivery and should be positioned at the top of the criteria for the successful outcome of every therapeutic approach (98). For example, clinicians may feel that the surgical treatment of a periodontally involved tooth is more effective in terms of long-term pocket-depth reduction than nonsurgical root debridement; however, the patients are more likely to be concerned about the effects of the therapy on their quality of life. Therefore, patient perceptions and expectations, together with patients' satisfaction and improvement in quality of life after treatment, should also be seriously considered during the treatment planning.

Currently there is a commonly held perception among clinicians and industry promoting implant dentistry that dental implants provide better quality-of-life outcomes than other conventional treatments, including periodontal therapy. This perception is partly based on clinical trials reporting on patient-centered treatment outcomes following the provision of implant-supported restorations, mainly for the treatment of complete edentulism (2, 37). In these studies, dental implants have been clearly shown to increase quality-of-life measures and enhance patient satisfaction when used as anchorage for removable full dentures (2, 37) or fixed partial dentures (61, 155, 173, 174) in comparison to conventional removable dentures or no prosthetic reconstruction. However, when implant-supported fixed dentures were used to restore smaller edentulous spaces, such as a single-tooth replacement, they did not offer any additional benefit in terms of quality of life over resin-bonded fixed dentures (153). Similarly, it has been reported that only 80% of patients were 'somewhat' satisfied or extremely satisfied with single-tooth implants (47).

Periodontal therapy often involves lengthy procedures that can inflict discomfort, moderate postoperative complications (such as root sensitivity) and unfavorable esthetic results from increased gingival recession. For these reasons, periodontal treatment may not be as effective in terms of patient satisfaction and may influence quality of life immediately after treatment. Besides the above concerns, it has clearly been shown that periodontal disease has a negative effect on patients' quality of life (100, 101, 125) while periodontal therapy has a positive long-term impact on periodontitis patients' quality of life (10, 15, 72, 83, 129, 162). However, the magnitude of this effect is still questionable and not comparable with other therapeutic approaches.

To date, there is no supporting evidence for the superiority of implant treatment over periodontal therapy or *vice versa* because there are no randomized controlled trials directly comparing patient-satisfaction levels and quality-of-life changes after treatments aimed at tooth retention vs. provision of dental implants (161). Many factors might influence patient satisfaction following both therapeutic approaches. These include age, gender, cost, occupation and socioeconomic class and cultural differences, as well as psychological characteristics (2, 72, 83, 129), and are often the same factors that may influence the decision to extract or retain a compromised tooth (11, 166). Therefore, these factors should be carefully evaluated during the pretreatment assessment.

Conclusion

An extensive evaluation of the patient's socioeconomic and psychological profile, together with attitudes and perceptions (e.g. opposed to or accepting implants), may set the threshold for a tooth of questionable prognosis to be retained or extracted and replaced by a dental implant.

Q: Are esthetics after conventional periodontal therapy as acceptable as those after implant therapy?

Patient's expectations regarding esthetics must be considered in any decision-making process in dentistry. Esthetics are a major concern for patients with periodontitis, and poor esthetics can relate to either disease progression or the consequences of successful periodontal therapy. Common reasons for poor appearance are gingival recession and clinical crown elongation, the loss of interdental papillae and drifting

or extrusion of teeth with a reduced periodontium. Unfortunately, in the advanced stages of periodontal disease, the soft- and hard-tissue deficiencies cannot be predictably prevented or treated.

Recently, the use of implants in the esthetic zone started to be documented based on well-defined esthetic parameters. Predictable soft-tissue contours can be achieved with single-tooth replacement in the esthetic zone as a result of the tissue support provided by the adjacent natural teeth (16, 17). However, the esthetics following replacement of multiple missing teeth with dental implants in the anterior maxilla may be unpredictable and esthetic failures following implant-supported restorations in the anterior dentition are common (49). Poor emergence profiles, loss or distortion of the papillae (29, 163) and exposure of the metallic implant components are the most common reasons for esthetic failures, which were mainly attributed to incorrect implant placement and insufficient hard- and soft-tissue volume (16, 49).

Ideally, an implant-supported restoration should be able to satisfy both the patient's and the dentist's esthetic expectations by successfully imitating the appearance of natural teeth and achieving symmetry with the adjacent dentition (16). To ensure that optimal esthetics can be achieved during implant rehabilitation, adequate bone volume, a sufficient amount of healthy peri-implant soft tissues and optimal implant position, are necessary. The esthetic difficulties encountered in providing implant-supported prostheses in areas where the soft and hard tissue volume has already been compromised (e.g. as a result of periodontal disease or post-extraction resorption) should be carefully considered before the extraction of periodontally compromised teeth. This is particularly important in patients with high esthetic demands and a thin mucosal biotype where the risk for esthetic implant failures is higher (52). It is important, however, to emphasize that preserving a periodontally compromised tooth with unsatisfactory esthetics in a visible position in the mouth may not be considered as a successful treatment outcome, even if all other clinical parameters are satisfactory (168).

Conclusion

The decision on whether to conserve or extract an esthetically compromised, periodontally involved tooth depends on the patient's smile line, gingival biotype and local bone availability, but most of all on the patient's expectations regarding the final esthetic outcome. Tooth extraction for esthetic reasons may be recommended if the prosthetic restoration (either implant supported or tooth supported) will significantly improve the esthetic outcome and satisfy the patient's expectations. Expectation management should be a key component of all treatment planning.

Summary

Lost teeth can be replaced with tooth-supported or implant-supported reconstructions. The latter is a treatment modality that is gradually increasing in incidence and sometimes leads to premature extraction of teeth. However, there is significant evidence to indicate that periodontally involved teeth can be maintained and used to provide function for a long time. Unlike for teeth, our knowledge on implant survival beyond 10 years is limited and is based on implant systems that are no longer available. At the same time, biological complications in the form of peri-implant mucositis, peri-implantitis and eventually implant loss are becoming increasingly prevalent.

Patient-related risk factors for peri-implant diseases have been identified and include smoking, poor oral hygiene and a history of periodontitis. Therefore, if implant treatment is considered in patients with periodontitis, a combined patient and site risk profile assessment, together with a cost–benefit analysis based on patient's expectations, should always be performed following an extended observation period after completion of periodontal therapy.

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