Effects of dental implants on hard and soft tissues
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Chapter 8

General discussion and conclusions
Implant dentistry is evolving rapidly. In a wide area of applications, dental implants have become a vital part of prosthodontic treatment. All these various applications will have different influences on the surrounding oral environment, especially on the hard and soft tissues. These influences can affect the direct surroundings of the implant, such as the peri-implant hard and soft tissues, but also the hard and soft tissues surrounding the adjacent teeth. In edentulous patients, next to the direct effect on the tissues in the vicinity of the implants, also indirect effects may occur on the tissues in regions further away from the inserted implants, e.g. on the antagonistic jaw or when the implants are placed in the interforaminal region, on the posterior regions of the mandible.

Taking these considerations into mind, a PhD research was performed to gain insight into the direct effects of dental implants on peri-implant hard and soft tissues and into the indirect effects on mandibular and maxillary residual ridge resorption in edentulous patients.

**Hard tissues**

**Posterior mandibular residual ridge resorption**

The posterior mandibular residual ridge resorption was assessed in the studies reported in chapter 2 and 3. The study reported in chapter 2 demonstrated that resorption of the posterior mandible was significantly less in patients treated with a four-implant overdenture compared to patients treated with a two-implant overdenture over a period of ten years. In chapter 3 patients were enrolled from the same previous prospective study, but as a result of other inclusion criteria fewer patients were included in the study groups. Although the mandibular residual ridge resorption in patients treated with two implants tended to be more than in patients treated with four-implant overdentures and conventional dentures, the difference between the groups was not significant. The least resorption of the posterior mandible was observed in patients treated with a four-implant overdenture. The more posterior position of the axis of rotation and less resilience of the bar superstructure on four implants might have exerted fewer forces on the posterior ridge and thus have resulted in less bone resorption. In addition, design related differences in loading patterns and movements of the denture have to be considered when looking for an explanation for the observed differences in posterior mandibular residual ridge resorption between the two and four implant overdenture patients. As it has been shown that an implant-retained overdenture improved the masticatory function
in patients (Stellingsma et al., 2005; Fueki et al., 2007). However, little is known about the exact changes with regard to the masticatory forces and the distribution of these forces under the denture as most studies have focused on the force distribution on the implants and not on the posterior residual ridge. When comparing the two-implant design with the four-implant design, rotation of the denture around a bar (no extensions) supported by two implants might result in an overall distribution of the masticatory forces that may result in an increased resorption of the posterior ridge while the more rigid four implant design directs the patient towards a more anterior loading of the denture as the denture is the most stable in that region. Furthermore, the inter-individual variability of the resorption ratios for the mandible were high, but comparable to earlier studies and are probably related to the multifactorial aetiology of bone resorption (Tallgren, 1972; Jacobs et al., 1992).

**Anterior maxillary residual ridge resorption**

The results described in chapter 3 revealed that in the mandibular overdenture groups, ongoing resorption of the anterior maxilla had occurred during the 10 years evaluation period, which was significant for both the two-implant and four-implant groups and not significant for the conventional overdenture group. These observations are in line with the findings of others showing gradual maxillary ridge resorption in patients wearing implant-retained overdentures (Saunders et al., 1979; Lechner & Mammen, 1996; Kreisler et al., 2003). As observed for resorption of the posterior mandible, again large inter-individual differences are present, which might be related to the multifactorial aetiology of bone resorption (Jacobs et al., 1993; Kreisler et al., 2003).

It has been suggested that the risk of developing conditions of the combination syndrome increases in persons wearing a mandibular implant-retained overdenture (Barber et al., 1990; Lechner & Mammen, 1996). Anterior maxillary ridge resorption was suggested to be a result of the posterior mandibular ridge resorption, both conditions being symptoms of the combination syndrome. However, the present study (chapter 3) failed to show a correlation between posterior mandibular residual ridge resorption and anterior maxillary residual ridge resorption. Furthermore, there were no significant differences in the maxillary residual ridge resorption between patients treated with an overdenture on two or four implants or treated with a conventional complete denture. Thus, the results of our study could not confirm the suggestion that the combination syndrome also may occur in maxillary dentures opposed by
an implant-retained mandibular overdenture. Several factors could contribute to the findings observed in our study. Firstly, all patients in our study were treated with a balanced occlusion and monoplane articulation concept to limit anterior pressure (Lang & Razzoog, 1992; Narhi et al., 2000). Secondly, optimal denture fit and therefore a more balanced stress distribution of the denture was achieved by paying special attention with regard to the prosthetic aftercare (Visser et al., 2009; Meijer et al., 2009). Finally, it could be that the long edentulous period (on average 20 years) before patients entered the study has affected the residual ridge resorption as most resorption already might have taken place.

**Peri-implant bone changes in edentulous patients**

The results of chapter 4 revealed that the location of the rough/smooth border and the location of the microgap did not have to be considered as major factors determining the marginal bone level after placement of implants in edentulous subjects during the first five years of functional loading.

To study the impact of the rough/smooth border on the marginal bone ITI-implants (one piece implant without a microgap in the vicinity of the marginal bone) were used. Based on the results of prior animal studies evaluating bone remodelling during the initial healing phase, the marginal bone level was not to be expected above the rough/smooth border at start of functional loading. After initial bone remodelling at start of loading, in one third of the implants the marginal bone level was still located above the rough/smooth border, i.e. at height of the smooth surface. In addition, in IMZ-implants both the rough/smooth interface and the microgap could affect the marginal bone changes. The implants were placed with the smooth portion of the implants neck subcrestal and the microgap aligning the crest of bone. In contrast to other studies reported in the literature (Hermann et al., 2000; Hartman & Cochran, 2004), in many of the patients the marginal bone level was still in the area between the microgap and the rough/smooth border, thus at the smooth surface. In addition, there were no significant differences measured in bone loss between the two IMZ-groups. Moreover, during the evaluation period of 5 years, in both the ITI-group and the IMZ-groups, the mean bone loss continued after crossing the rough/smooth border. Thus we like to pose that the state of the surface (rough versus smooth) apparently has no major impact on the marginal bone level in the edentulous mandible during functional loading.
In animal studies, it was shown that in 2-piece implants the microgap determines the first bone to implant contact (Hermann et al., 2000; Assenza et al., 2003; Piattelli et al., 2003). A contaminated microgap would be isolated by apical migration of the epithelium beyond the microgap and its bacteria. This migration of the epithelium and subsequent response to re-establish the dimension of the biological width has been posed to be responsible for the approximately 2 mm of distance that was present apical to the microgap in those experiments after initial bone remodelling (Hermann et al., 2001; Piattelli et al., 2003). The results of the IMZ implants demonstrated that a marginal bone level within 2 mm, even within 1 mm from the microgap is not an exception 6 months after placement at start of functional loading the implants. Moreover, in spite of the different locations of the microgap after implant placement for the various implant designs studied, there were no significant differences in mean bone loss between the IMZ-groups and the ITI group, other than a larger variation in bone levels around IMZ implants than around ITI implants. This observation might indicate that marginal bone changes around IMZ implants is less predictable and more prone to patient factors. In addition, these results seem to indicate that the location of the microgap has no major impact on the marginal bone level in the edentulous mandible.

It has to be remarked, however, that in most patients in our study the implants had been placed in severely resorbed mandibles. Thus, the outcomes of the present study reflect the marginal bone resorption around implants placed in the severely resorbed mandible whereas the majority of papers reporting on bone loss refer to implants placed in jaws still including the alveolar processes (Weber et al., 2000; Chou et al., 2004; Hartman & Cochran, 2004; Hanggi et al., 2005).

**Peri-implant bone changes in partially dentate patients**

The results of the retrospective study evaluating the clinical outcome of adjacent implants in the aesthetic zone, described in chapter 5, revealed that the inter-implant bone crest level was positioned significantly more apically than the bone crest level between an implant and its neighbouring tooth. The observed reduced inter-implant bone crest level was probably the result of two factors. Firstly, the inter-implant distance seems to influence the inter-implant bone crest level; a inter-implant distance of less than 3 mm, will result in an increased loss in the height of the inter-implant bone crest level as a result of the lateral component of peri-
Implant marginal bone loss. Overlap of both resorption areas between the adjacent implants will eventually result in vertical reduction of the inter-implant bone crest level (Tarnow et al., 2000; Cardaropoli et al., 2003; Gastaldo et al., 2004). Secondly, the inter-implant bone crest level was determined by the bone crest level at the moment of insertion of the implants. The study group described in chapter 5 consisted of merely augmented patients with an already compromised bone condition at baseline. At time of implant placement, the bone crest level between two adjacent implants was at most equal, but not uncommon already positioned more apically than the marginal bone level of the adjacent teeth.

The clinical trial reported in chapter 6 revealed a significantly higher mean marginal bone loss approximal of implants with a scalloped platform than approximal of implants with a flat platform during the period from implant insertion up to 12 months after placement of the definitive crown. The marginal bone loss of the scalloped implants even exceeded the criteria of success stated by (Albrektsson et al., 1986). The flat implant group did meet these criteria of success. Apparently, the marginal bone level did not follow the scalloped three-dimensional platform of the implant design, as it was meant to do. An explanation for the excessive bone loss around the scalloped implants might be that the lower lingual and facial part of the implant platform determined the marginal bone level around the implant. Furthermore, the mean inter-implant bone crest loss was significantly higher when scalloped implants were applied. This is probably predominately the result of two factors. Firstly, the higher mean marginal bone loss approximal of the scalloped implants probably has resulted in a larger horizontal component of the peri-implant bone loss. Secondly, the mean horizontal distance of 3.2 mm between adjacent scalloped implants was significantly smaller than the mean horizontal distance of 3.8 mm between adjacent flat implants. This is partly due to the design of the NobelPerfect narrow platform implant that was placed at the position of the lateral incisor. The implant neck of the NobelPerfect narrow platform implant, the most narrow implant of the NobelPerfect implants, still has a diameter of 4.31 mm, whereas the ReplaceSelect narrow platform implant has a diameter of 3.54 mm.

Chapter 7 described a pilot study comparing an implant crown with a cantilever versus two implants with solitary implant crowns to restore a missing adjacent upper central and lateral incisor. The results showed no differences between the groups with regard to the marginal bone loss and the bone crest loss. The mean marginal bone loss was comparable with other
studies (Friberg et al., 2005; Fischer et al., 2009). On the other hand, the mean marginal bone loss at the side of the implants facing the cantilever tended to be slightly larger in comparison to the other approximal implant sides of the implant-cantilever group and the implant-implant group. Mean bone crest resorption distally of the central implant in the implant-cantilever group was comparable with the mean inter-implant bone crest resorption between the central implant and the lateral implant in the implant-implant group. Rather large standard deviations were observed for the mean changes in marginal bone level and crestal bone level which might point towards considerable variability in changes in bone level between individual patients. Comparable observations were reported in other studies (Steveling et al., 2001; Wennstrom et al., 2005; Meijndert et al., 2008).

General conclusions regarding hard tissues

- When compared to patients wearing a two-implant overdenture, mandibular posterior residual ridge resorption is slightly reduced in patients wearing a four-implant overdenture.
- There was no difference in anterior maxillary residual ridge resorption between patients rehabilitated with an implant-retained mandibular overdenture when compared to patients wearing a conventional full denture.
- Location of the rough/smooth border and location of the microgap does not have to be considered as major factors determining the marginal bone level around dental implants in the severely resorbed human mandible during functional loading of TPS coated implants.
- After one year of function significantly more marginal bone loss and inter-implant crestal bone loss had occurred in patients treated with two adjacent scalloped implants than in patients treated with two adjacent flat implants in the aesthetic zone.
- Within the limitations of the pilot-study, peri-implant bone changes in patients treated with an implant crown with a cantilever and in patients treated with two adjacent solitary implant crowns to restore a missing adjacent upper central and lateral incisor were shown to be comparable after one year of function.
Soft tissues

Papilla index

The results of the clinical studies reported in chapters 5, 6 and 7 show that a papilla was more frequently present between an implant and its neighbouring tooth than between two adjacent implants. In all studies performed the inter-implant papilla indices scores were low, pointing towards a compromised papilla presence. In addition, there were no significant differences in papilla scores between patients treated with two adjacent scalloped implants and patients treated with two adjacent flat implants after one year of function. Furthermore, in patients with a missing adjacent central and lateral incisor, there were also no large differences in the frequency distribution of the papilla scores between patients treated with two adjacent solitary implant crowns and patients treated with a one implant with a cantilever after one year of function.

Features that are thought to affect the presence of an inter-implant papilla are the inter-implant bone crest level and the reduced soft-tissue height between two adjacent implants. As described in detail in the hard tissues section of the general discussion, the inter-implant bone crest level was commonly reduced as a result of an already compromised level at baseline together with the bone crest resorption after implant placement (Tarnow et al., 2000; Cardaropoli et al., 2006). As the soft-tissue follows the contour of the hard tissues, the reduced inter-implant bone crest height resulted in a compromised papilla presence between adjacent implants. Even more, between two adjacent implants only a soft tissue height of 3-4 mm should be expected instead of 5 mm soft-tissue height between an implant and a tooth (Tarnow et al., 2003; Gastaldo et al., 2004). Our results are in line with the findings of previous studies (Tarnow et al., 1992; Gastaldo et al., 2004; Kourkouta et al., 2009).

Marginal gingiva changes

The changes in marginal gingiva level were assessed in the clinical trial described in chapter 6. The results revealed that the changes in marginal gingiva level around the flat implants that occurred from implant placement up to twelve months after placement of the definitive crown were very small, indicating that the soft tissues around the flat implants and their neighbouring teeth had remained rather stable during the 18 months after implant insertion. These results were comparable with the results of other studies reporting on single tooth replacements
(Jemt & Lekholm, 2005; Meijndert et al., 2008). During the period between one month and twelve months after placement of the definitive crown marginal gingiva recessions were significantly larger for scalloped implants at the approximal side facing the adjacent implant and midbuccally in comparison with flat implants. Furthermore, the marginal gingiva levels around scalloped implants tended to be less stable than around flat implants, but changes were small. During the period from the evaluation visit prior to implant placement to twelve months after placement of the definitive crown, the loss in marginal gingiva midbuccally of the neighbouring teeth was higher in patients of the scalloped implant group than in patients of the flat implant group. No logical explanation could be ascribed to this difference between the groups because the implant insertion procedure did not differ between the groups.

Pocket probing depths
In all studies described in chapters 5, 6 and 7, the outcomes of the pocket probing depths revealed that the mean pocket probing depth around the implants was deeper than around the neighbouring teeth. The observed values and difference between implants and natural teeth were in agreement with the results of other studies (Bragger et al., 1997; Hultin et al., 2000; Meijndert et al., 2008). This is partly due to the biological width being different around natural teeth compared with implants (Cochran et al., 1997), which might result in a stronger resistance to probing in a gingival sulcus around natural teeth when compared with a mucosal seal around implants (Ericsson & Lindhe, 1993). Furthermore, the in chapter 6 described results indicate that the mean pocket probing depths were significantly deeper around scalloped implants than around flat implants. The results of the flat implant group were comparable with results reported on single tooth replacements (Wennstrom et al., 2005). The studies published thus far on scalloped implants did not report on pocket probing depth, therefore it was impossible to compare the results of the present study with the literature. The significantly deeper peri-implant pockets around scalloped implants are most likely the result of the more apical situated marginal bone level around the scalloped implants. The bottom of the peri-implant pockets is determined predominantly by the marginal bone level, whereas the top of the peri-implant pockets is determined by the top of the marginal gingival level. The marginal gingiva is held up by the most coronal level of the underlying bone which is assessed in this study as the inter-implant bone crest level between two adjacent implants and the implant-tooth bone crest.
level between an implant and its adjacent tooth. Furthermore, the mean pocket probing values around the implants in the implant-cantilever group and the patients of the implant-implant group were comparable (chapter 7); the presence of a cantilever and possible moment forces on the implant seemed to have no or a negligible negative effect on the pocket probing depth.

Aesthetic outcome

In the studies described in chapters 5, 6 and 7, patients’ satisfaction was evaluated. In all studies the results demonstrated that the patients were very satisfied with the aesthetic outcome. No significant differences were observed between the scalloped implant group and the flat implant group (chapter 6) and between the implant-cantilever group and the implant-implant group (chapter 7).

With regard to the overall scores of the aesthetic index, no differences were observed between the scalloped implant group and the flat implant group. The overall scores of the aesthetic index were relatively low. Moreover, professionals and patients were less satisfied with the appearance of the mucosa than with the appearance of the implant crown. It should be recognised that the aesthetic index was assessed at twelve months after placement of the definitive crown and this assessment did not include an assessment of the baseline aesthetics (many patients had compromised baseline aesthetics). In other words, the low aesthetic index score of the mucosa might be partly a result of the already compromised situation at start as more than half of the cases had to be reconstructed by an augmentation procedure prior to implant placement. Therefore, the mucosa had been subjected to several traumatic surgeries (Meijndert et al., 2007). Furthermore, the inter-implant papilla regeneration, an item which is judged by the aesthetic index, was in many cases compromised.

Although the opinion of the professional with regard to the aesthetic outcome scores was critical, the patients were very satisfied with the overall result. This difference in opinion is in accordance with other studies assessing single tooth replacements (Chang et al., 1999; Vermeylen et al., 2003; Palmer et al., 2007). A reason why the patients appreciated their aesthetics could be that they were informed of the consequences and risks of implant placement prior to treatment and accepted the limitations of the treatment. Additionally, while the professionals solely rated the final treatment outcome not taking the starting point into consideration, patients were very aware of their dentition prior to treatment; the final result
was probably very satisfactory to the patients’ opinion. Furthermore, factors often considered by professionals to be of significance for the aesthetic result of restorative therapy may not be of decisive importance for patient satisfaction (Chang et al., 1999).

General conclusions regarding soft tissue

- It is difficult to create a complete fill of the proximal space between two adjacent implant crowns.
- After one year of function, no significant differences were observed with regard to the papilla index between patients treated with two adjacent scalloped implants and patients treated with two adjacent flat implants.
- Patient satisfaction with regard to two adjacent implant crowns placed in the aesthetic zone is very high. After one year of function there were no significant differences regarding patient satisfaction between patients treated with two adjacent scalloped implants and patients treated with two adjacent flat implants.
- After one year of function, patients treated with two adjacent scalloped implants exhibited deeper pockets and more marginal gingiva recession around the implants than patients treated with two adjacent flat implants.
- Apparently it is difficult to establish predictable and harmonious soft tissues meeting the professionals’ standards around two adjacent implant crowns for the rehabilitation of two missing adjacent teeth in the aesthetic zone.
- Within the limitations of the pilot study, it was concluded that peri-implant soft-tissue changes and patient satisfaction in patients treated with an implant crown with a cantilever and in patients treated with two adjacent solitary implant crowns to restore a missing adjacent upper central and lateral incisor were comparable after one year of function.

Future considerations

In this PhD study the peri-implant hard and soft tissues around adjacent implants treated with a flat platform design and a scalloped platform design were evaluated. As new implant designs are still launched on the dental market, it is worthwhile to examine the influence of other new promising implant concepts, e.g. platform switching, on the peri-implant tissues regarding adjacent implants.
With regard to the results of our prospective clinical trial comparing implants with a scalloped platform and a flat platform, a longer follow-up is needed to assess the stability of the peri-implant hard and soft tissues around both implant designs over time, especially at inter-implant sites.

With regard to the pilot study, evaluating patients with a missing central and lateral upper incisor and treated with either one implant crown with a cantilever or two implants with solitary crowns, the results with regard to the peri-implant hard and soft tissues of both groups were comparable. A larger number of patients have to be studied to confirm our findings. The number of patients needed for such a study should be based on a power analysis using the results of our pilot study as input data.

The pre-treatment conditions of the site might have a certain impact on the aesthetic outcome. Unfortunately the aesthetic assessment scales yet available in the literature do not include a baseline assessment. This might explain partly the differences in aesthetic outcome between patients (taking the baseline aesthetics into consideration) and professionals (just rating the final result). Next to complementing the aesthetic assessment scales with a baseline assessment, it would be interesting to assess pre-treatment clinical and radiographic variables and to evaluate how and to what degree these variables determine the aesthetic outcome. Such information would be of great value to the dental practitioner as such information might help the practitioner to predict the aesthetic outcome for the individual patients.
Chapter 8

References


