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Clinical relevance of dimensional bone and soft tissue alterations post-extraction in esthetic sites

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The development of predictable and innovative implant therapies for optimal esthetic outcomes requires a thorough understanding of the underlying biological processes of bone and soft tissue healing following tooth extraction (16). In the past, research focused on better understanding the osseointegration process, and as a result implant surface topography/chemistry has been profoundly investigated and markedly improved (22, 46, 81, 96). These innovations have contributed to reduced healing periods and the use of short or narrow diameter implants (5, 59). Predictable osseointegration leads to successful implant function over time, which can be assessed by the success criteria proposed by Albrektsson et al. (2), Buser et al. (23) and others. However, successful implant function alone does not fulfill the increasing demands of today's patients and clinicians for pleasing esthetics.

Attaining pleasing esthetics in the anterior maxilla involves many clinical parameters but is principally related to the peri-implant mucosal architecture in comparison with the contra-lateral natural tooth (31). The peri-implant mucosa needs to be supported by an adequate three-dimensional (3D) osseous volume of the alveolar ridge, including an intact facial bone wall of sufficient thickness and height in combination with correct restoration-driven implant positioning (21, 42, 47). Deficiency of the facial bone anatomy has a negative impact on esthetics and is a critical causative factor for esthetic implant complications and failures (28). However, the integrity of the hard and soft tissue dimensions is jeopardized by physiological and structural changes following tooth loss (11). Experimental and clinical research provides important knowledge about related biological events and the extent of dimensional alterations following tooth extraction, as well as how they can be minimized in order to maintain the natural soft and bone tissue architecture of the dentition over time.

The aim of this review is to summarize the degree of tissue alterations in single tooth extraction sites of the anterior maxilla and to identify associated modulating factors in order to assist the clinician in the selection of the most appropriate treatment protocols to facilitate pleasing esthetic treatment outcomes.

Degree of dimensional tissue alterations following tooth extraction

Bone alterations following tooth extraction

Experimental studies

The dimensional and structural alterations following tooth extraction have been studied in detail in mandibular premolar sites of beagle dogs (8, 25) (Fig. 1). These catabolic changes are initiated by the resorption of the bundle bone that lines the extraction socket. The bundle bone, consisting of lamellar bone, has a thickness of 0.2–0.4 mm and is a tooth-dependent structure (79) (Fig. 1A). The catabolic changes have been correlated with the disruption of the blood supply from the periodontal ligament, which subsequently leads to significant osteoclastic activity (8, 25). As the bundle bone is a tooth-dependent structure, it is gradually resorbed following tooth

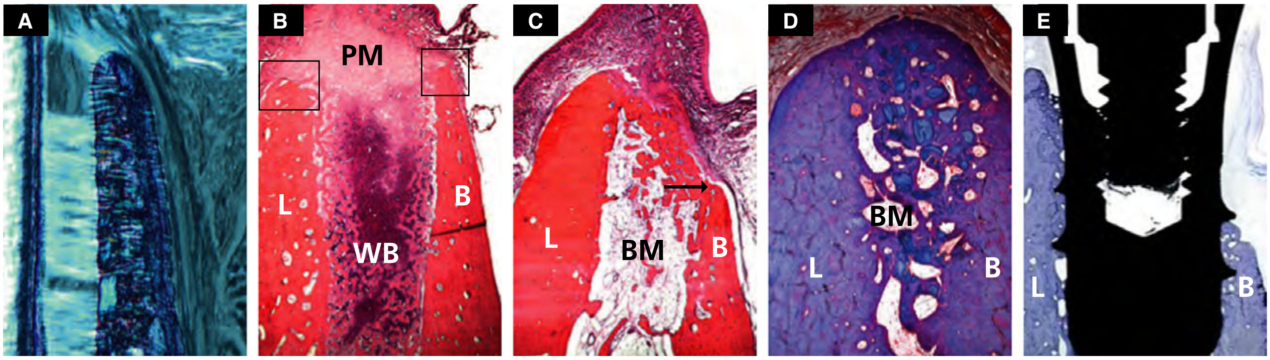


Fig. 1. (A) Buccal–lingual section illustrating the most coronal portion of the buccal bone wall. The buccal wall is made up mainly by bundle bone. Polarized light. Toluidine blue stain; original magnification × 50 (with permission from Ref. (11)). (B) Overview of the extraction site after 2 weeks of healing. Note large amounts of woven bone are present in the lateral and apical portions of the socket. B, buccal; L, lingual; PM, provisional matrix; WB, woven bone. Hematoxylin-eosin staining; original magnification × 16 (with permission from Ref. (8)). (C) Overview of the extraction site after 8 weeks of healing. The entrance of the socket is sealed by a hard tissue ridge that comprises woven bone and lamellar bone. The central portion of the socket is dominated by bone marrow. Note that the marginal portion of the buccal wall (arrow) is about 2 mm 'apical' of the marginal termination of the lingual wall. B, buccal; BM, bone marrow; L, lingual; arrow, marginal portion of the buccal wall. Hematoxylin-eosin staining; original magnification × 16 (with permission from Ref. (8)). (D) Microphotograph of a buccal–lingual section representing a grafted site. Note the large number of Bio-Oss particles that are present in the healed extraction socket. B, buccal bone wall; BM, bone marrow; L, lingual bone wall. Ladewig fibrin stain; original magnification × 7 (with permission from Ref. (10)). (E) Buccal–lingual section representing an implant site after 3 months of healing. Note the location of the bone crest at the buccal and lingual aspects of the implant. The level of bone-to-implant contact was located 2.6 mm (B, buccal aspect) and 0.2 mm (L, lingual aspect) apical of the sand-blasted and acid-etched level. Toluidine blue staining; original magnification × 16 (with permission from Ref. (12)).

extraction, leading to a vertical bone loss of about 2.2 mm in mandibular premolar sites on the facial aspects (8). In contrast, minimal bone resorption has been observed on the lingual aspect (Fig. 1B,C). This phenomenon has been attributed to the limited thickness of the facial bone wall in comparison with the lingual/palatal aspects of the socket (8). Socket grafting has shown to modify these modeling events and to partially counteract the marginal ridge contraction that occurs following tooth removal (10) (Fig. 1D). Immediate implant insertion into a fresh extraction site failed to prevent the remodeling that occurred in the walls of the socket. The resulting height of the buccal and lingual walls at 3 months was similar at implant and edentulous sites. The vertical bone loss was more pronounced at the buccal than at the lingual aspect of the ridge and amounted to 2.6 mm apical of the sand-blasted and acid-etched level (12) (Fig. 1E). Full maintenance of the facial bone wall dimension has been observed for a bone wall thickness of 2 mm following immediate implant placement in an experimental dog study (74). However, post-extraction dimensional alterations appear to be related to several additional factors, including surgical trauma due to flap elevation, lack of functional stimulus on the remaining bone walls and a lack of periodontal ligament and genetic information (11).

Clinical studies

In humans, dimensional alterations have been reported to cause a ridge width reduction of up to 50% during the first year following tooth loss in premolar and molar sites, where two-thirds of the total changes take place within the first 3 months post-extraction (80). A systematic review showed a loss of 2.6–4.5 mm in width and 0.4–3.9 mm in height of healed sockets (86). The healing events of extraction sockets have also been examined in human biopsies taken at various time points after extraction (88). It was shown that the density of vascular structures and macrophages slowly decreased from 2 to 4 weeks, the level of osteoclastic activity slowly decreased over a 4-week period, whereas the presence of osteoblasts peaked at 6–8 weeks and remained almost stable thereafter.

The extent of bone loss following extraction seems to depend on factors such as facial bone wall thickness, angulation of the tooth, and other differences in anatomy at the various tooth sites (66). The width of the facial socket wall is either analysed intraoperatively 1 mm below the alveolar crest (52), or measured by cone beam computed tomography at different levels (18, 55, 89). The facial bone wall thickness in the anterior maxilla has been shown to be less than 1 mm in 90% of cases and less than 0.5 mm in almost 50% of cases (18, 52, 55, 89). Hence, such thin facial bone walls, consisting mainly of bundle bone, appear to be prone to resorption following tooth extraction. In a clinical cone beam computed tomography study of 39 patients, a progressive bone resorption pattern was observed in sites with a facial bone wall thickness of 1 mm or less, leading to a median vertical bone loss of 7.5 mm or 62% of the former facial bone height after 8 weeks of healing (26) (Fig. 2). In contrast, patients with a thick wall phenotype, showing a facial bone wall thickness of more than 1 mm, displayed only a median vertical bone loss of 1.1 mm or 9%. The dimensional alteration pattern in single extraction sites with healthy neighboring dentition occurred mainly in the central area of the socket wall, whereas the proximal areas remained nearly unchanged after flapless tooth extraction at 8 weeks of healing (Fig. 2).

Clinical recommendations regarding dimensional bone alteration

The assessment of the facial bone wall thickness provides the clinician with a prognostic tool to estimate the degree of future bone loss prior to tooth extraction. It is important to note that dimensional bone alterations observed in patients are 2–3.5 times more severe than those seen in experimental studies (3, 8, 12, 26, 37, 92). Post-extraction bone modeling in single-tooth extraction sites seems to be localized to the central, mid-facial aspect of the socket wall at 8 weeks post-extraction, while proximal areas are well supported by the periodontal ligament (PDL) of the neighboring teeth and show no bone loss (28). Such a bone resorption pattern results in a two-wall defect morphology in thin bone wall phenotypes in which the facial bone wall has been partially resorbed, and in a three-wall morphology in sites with an intact thick facial bone wall phenotype (26). The high regenerative potential of two- and three-wall peri-implant bone defects has been attributed to the ratio between the area of exposed bone marrow and the defect volume to be regenerated (77). As discussed earlier, studies have shown that the initial osteoclastic activity decreased at 8 weeks, whereas the osteoblastic activity remains high (8, 25, 88), providing favorable conditions for regenerative procedures (19, 76). Therefore,

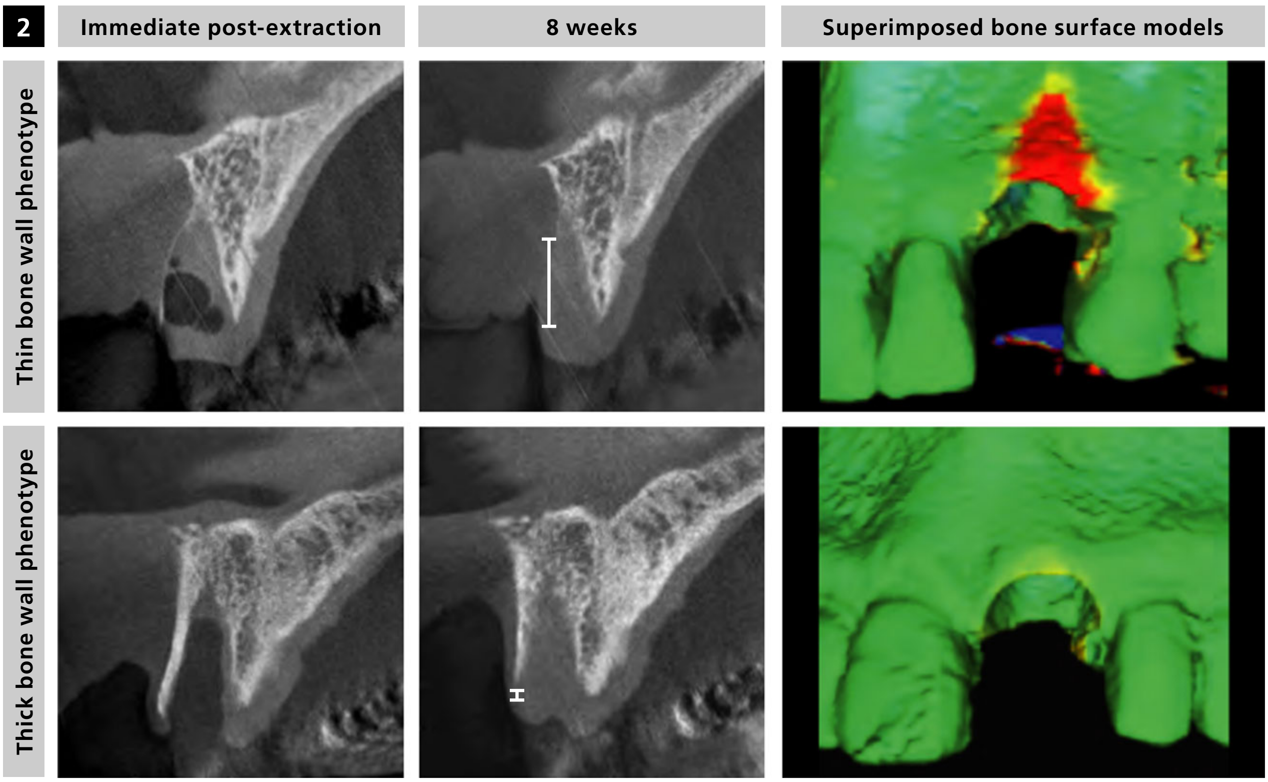


Fig. 2. Thin bone wall phenotypes with a facial bone wall thickness of 1 mm or less, revealed a progressive bone resorption pattern, leading to median vertical bone loss of 7.5 mm or 62% of the former facial bone height after 8 weeks of healing. This is in contrast to thick wall phenotypes, showing a facial bone wall thickness of more than 1 mm, displaying only a median vertical bone loss of 1.1 mm or 9%. The dimensional alteration pattern in single extraction sites with healthy neighboring dentition occurred mainly in the central area of the socket wall, whereas the proximal areas remained nearly unchanged after flapless tooth extraction at 8 weeks of healing (with permission from Ref. (26)).

in thin bone wall phenotypes, the initial and physiological post-extraction bone modeling phase should be waited for, in order to facilitate bone regenerative procedures. This protocol has been adopted for early implant placement, where a healing period of 4–16 weeks is used prior to implant insertion (50), and has been recommended as the treatment of choice in sites exhibiting a progressive bone resorption pattern, such as the thin bone wall phenotypes (67). An immediate implant placement protocol can be recommended in thick bone wall phenotypes and thick gingival biotypes, where the post-extraction bone modeling is expected to be minimal (67). However, if such ideal conditions are not present, other implant timing protocols are recommended in order to provide predictable esthetic treatment outcomes (67, 94).

Soft tissue alterations following tooth extraction

Soft tissue dimensions prior to tooth extraction

Even though the soft tissue texture, color and appearance plays a pivotal role in achieving pleasing esthetics (15), the influence of soft tissue healing in post-extraction sites has received little attention in clinical research (82). Thicker soft tissues not only have a higher volume of extracellular matrix and collagen, but also increased vascularity, which enhances the clearance of toxic products and favors the immune response (53, 70). Therefore, thicker soft tissues have been shown to respond more favorably to wound healing, flap management and restorative trauma, not only in periodontal (53) but also in implant surgery (35, 91). Prior to extraction, the facial soft tissue thickness in the anterior maxilla by nature is thin in most patients, ranging between 0.5 and 1 mm (41, 68, 83). No significant correlation has been found between soft tissue thickness and the underlying facial bone wall thickness (27, 40, 99). Several surgical techniques have been developed to effectively increase the soft tissue volume and are routinely used by clinicians (58, 87).

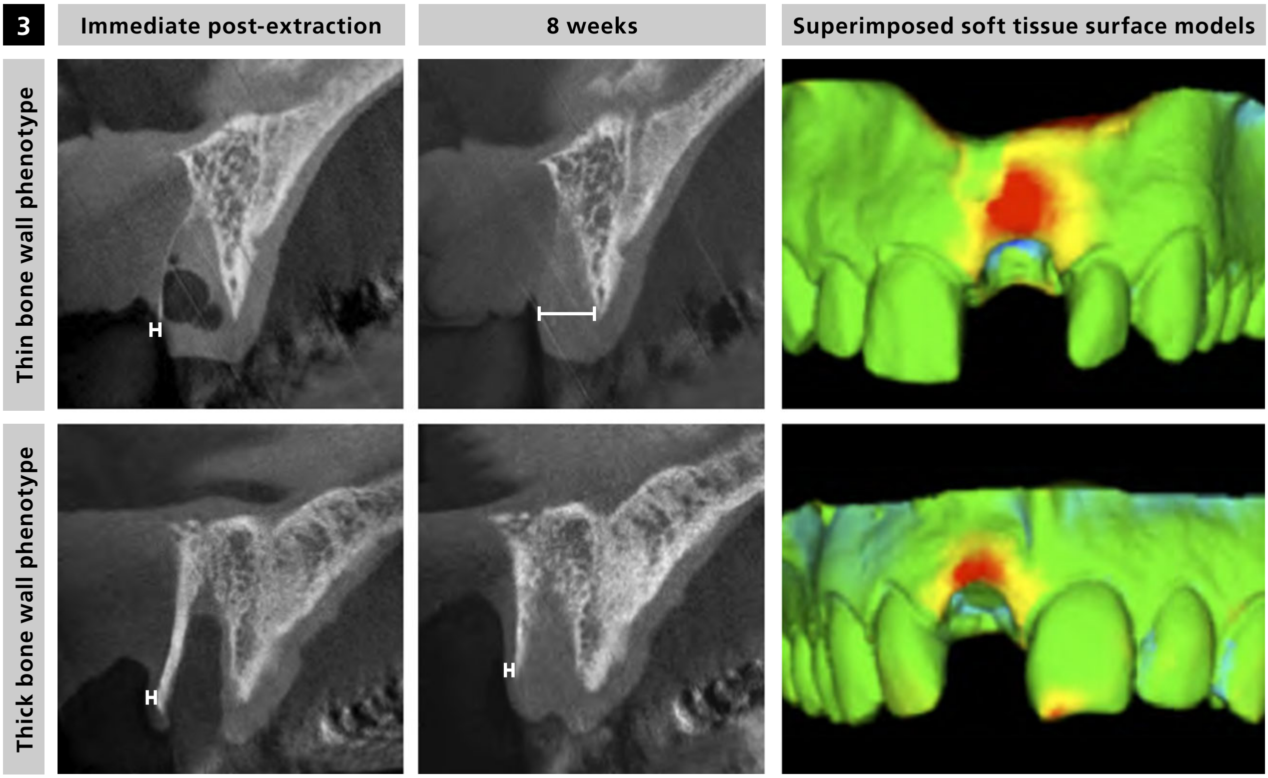
Soft tissue dimension post-extraction

As in fracture repair, wound healing of extraction sockets is a complex process that requires spatially and temporarily regulated expression as well as coordinated interplay between many different types of tissues and cells (43, 48, 61). The current understanding of soft tissue healing and regenerative strategies is mainly based on cutaneous wounds (70). In contrast to cutaneous wounds, mucosal wounds heal with only minimal scar formation and exhibit an accelerated healing pattern (45, 84, 85). The favorable healing of the oral mucosa is characterized by a faster resolution of inflammation and control of myofibroblast action compared with skin wounds (64). Extracellular matrix components revealed similarities between oral and fetal tissue, which eventually play a role in the favorable healing events between these two tissues (44). This might indicate that some extracellular matrix components are involved in the mode of repair. However, knowledge of dimensional alterations of the overlying facial soft tissues is scarce and their contribution to post-extraction bone modeling is poorly understood (27).

Dimensional soft tissue changes post-extraction have been examined in single tooth extraction sites (27). Overall, more than 50% of these changes occur very quickly, within 2 weeks of healing. The soft tissue thickness increases significantly depending on the underlying bone dimensions (27) (Fig. 3). In thick-wall phenotypes, the alveolus provides a self-contained bony defect, which favors the ingrowth of progenitor cells from the bony socket walls and the surrounding bone marrow space. In such thick bone wall phenotypes, the soft tissue dimensions on the facial aspect remain unchanged during healing (27) (Fig. 3). This is in contrast to thin bone wall phenotypes, in which the soft tissue dimensions revealed a sevenfold spontaneous increase after healing which was termed spontaneous soft tissue thickening (Fig. 3). It may be hypothesized that the rapidly resorbing thin facial bone wall favors facial soft tissue ingrowth due to its high proliferative rate. Subsequently, these soft tissue cells occupy the majority of the available space in the crestal area of an extraction socket defect. A highly vascularized granulation tissue is formed and fibroblasts migrate into the wound (48). Some of these fibroblasts differentiate into myofibroblasts, which stabilize wound margins and may be involved in the thickening phenomenon (60). A trend toward soft tissue thickening following tooth extraction has also been shown in other studies (36, 54, 56, 78). On a molecular level, soft tissue thickening at 8 weeks is paralleled by a peak in endothelial cell density, in bone morphogenetic protein-7 and in osteocalcin expression (88). Therefore, the molecular and cellular mechanisms that control new bone formation may also influence soft tissue thickening (1, 43).

Clinical recommendations regarding dimensional soft tissue alterations

The facial soft tissue thickens spontaneously in sites where progressive bone resorption of the former socket walls occurs (27). This spontaneous soft tissue thickening in thin bone wall phenotypes after an 8-



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week healing period offers several advantages during implant surgery. First, the spontaneous soft tissue coverage after healing provides an increased amount of keratinized mucosa, which facilitates primary flap closure and favors bone regeneration (19, 35, 71, 98). Second, the spontaneously thickened soft tissue volume may reduce the need for additional soft tissue grafting, limiting morbidity and treatment costs. However, these spontaneously thickened tissues may mask the true extent of an underlying bone defect during the clinical examination and may subsequently mislead clinicians in the selection of the appropriate treatment protocol (67).

Factors influencing the degree of dimensional alterations

Over the past two decades it has become evident that post-extraction dimensional alterations inevitably occur due to the resorption of the bundle bone as a tooth-dependent structure, and to related factors such as a lack of functional stimulus and a lack of vascular blood supply due to the missing periodontal ligament and genetic information (11). Even though numerous bone and soft tissue augmentation techniques have been suggested for regenerating the lost tissue structures (65), establishing clear guidelines for facilitating implant placement and achieving predictable treatment outcomes remain a significant challenge in clinical practice (13). Several surgical techniques have the potential to modulate the degree of these inevitable changes, such as flapless tooth extraction, ridge preservation and immediate implant placement.

Flapless tooth extraction

Even though tooth extraction has been considered a simple and straightforward procedure, it should be performed with care and under the assumption that dimensional ridge alterations will follow (11). Tooth extraction is an invasive procedure, since it disrupts vascular structures and damages soft tissues and the associated periodontal ligament (25). Flapless tooth extraction is important to avoid additional bone resorption from the bony surface related to the elevation of the mucoperiosteal flap (97). Flapless tooth extraction has been shown to reduce the amount of bone loss in the early healing phase 4–8 weeks post-extraction compared with full-thickness flap elevations (38), whereas after a healing period of 6 months, no differences were observed regarding bone loss with or without flap elevation (9). Therefore, a flapless low-trauma tooth extraction approach is recommended in cases of immediate implant placement in sockets with thick facial bone wall phenotypes and when using early implant placement protocols (Type 2, 3) in order to avoid additional bone loss at the superficial bone wall (20, 50). The extraction itself should be performed without applying force toward the thin facial bone wall. Several new surgical instruments and approaches are available to promote low-trauma tooth extraction, such as periotomes, piezosurgery and vertical tooth extraction devices (69, 90). If these techniques are not applicable, a separation along the longitudinal root axis in the oro-facial direction is recommended in order to minimize pressure on the facial bone wall and to make it possible to remove the root fragments separately.

Ridge preservation techniques

Even though attempts to preserve the ridge have failed to arrest the inevitable biological process of dimensional ridge alterations post-extraction, in particular with respect to the preservation of the alveolar bone volume, studies have shown that grafting of extraction sockets with biomaterials and the use of barrier membranes is able to reduce the degree of dimensional alterations (7, 10, 13).

Maintenance of the root

Early therapeutic attempts to prevent alveolar ridge resorption were performed using root retention, with the primary goal of maximizing the stability of removable prostheses (72). Clinical studies have tested the hypothesis that root retention by decoronation of the crown at the bone level is able to reduce ridge alterations and to maintain existing bone volume dimensions (4, 39). Other authors have suggested maintaining a facial shield of a root remnant simultaneously with implant placement, with the aim of preserving the facial bone architecture (14, 51). However, root retention with simultaneous implant placement is rarely feasible due to infection, fracture, or decay of the affected tooth or for strategic reasons. If compromised roots are maintained in close contact with an implant they may cause severe damage to the neighboring implants (62).

Socket grafting

Socket grafting has gained in popularity in recent years due to its conceptual attractiveness and technical simplicity (30). A large variety of biomaterials have been employed and tested in several studies, including autologous bone, bone substitutes (allografts, xenografts and alloplasts), autologous blood-derived products and bioactive agents (34). An experimental study demonstrated that in untreated extraction sockets, about 50–60% of the tissue was newly mineralized bone after 3 months of healing, whereas in sites grafted using deproteinized bovine bone mineral only 12% of the former socket was occupied by newly mineralized tissue (6). This implies that new bone formation is delayed in the earlier healing phase in grafted sites. A recent randomized clinical trial in 14 patients revealed that socket grafting failed to preserve the resorption of the buccal and palatal bone walls after 4 months of healing. However, the deproteinized bovine bone mineral particles were integrated with the newly formed host bone and retained the volume of the hard tissue defect, although the buccal and to some extent also the palatal bone plates were markedly diminished (7). The Osteology Consensus Conference in 2012 concluded that the majority of studies and systematic reviews did not reveal significant differences between various biomaterials and treatment approaches. Although primary wound closure was considered an important factor, the literature did not allow for a meaningful comparison of different techniques (49). A recent systematic review revealed that wound closure, the use of a membrane and the application of a xenograft or an allograft resulted in better outcomes than unassisted healing, showing a mean effect of 1.9 mm in terms of bucco-lingual width and 2.1 mm for the mid-buccal height (13) (Fig. 4).

Immediate implant placement

It has been suggested that placement of implants into fresh extraction sockets with a bone-to-implant gap of 2 mm or less would prevent remodeling and hence maintain the original shape of the ridge (73). However, findings reported from a clinical study by Botticelli et al. (17) failed to support this hypothesis. After 4 months of healing the outer surface of the buccal and lingual bone walls was markedly diminished, with a mean reduction of 56% in the buccal aspect and 30% in the lingual aspect. These findings were supported by an experimental study revealing a

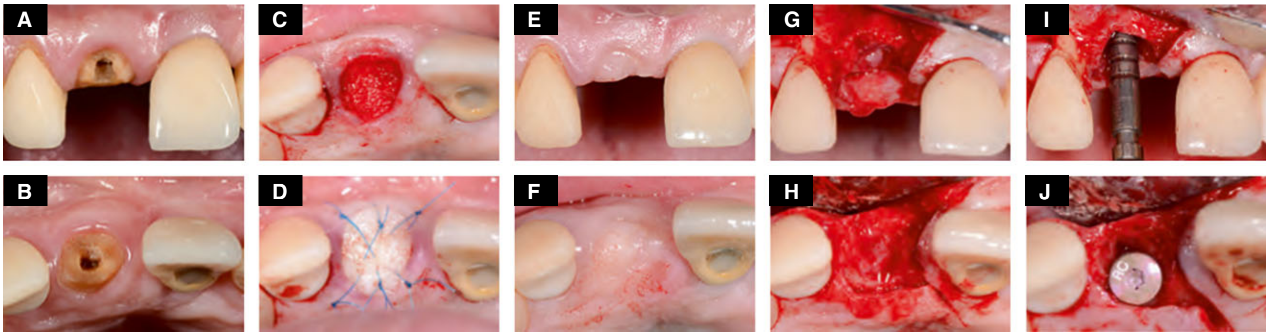

Fig. 4. A longitudinal fracture occurred in the right central incisor, which necessitated root removal. Adjacent to the fractured root a single implant restoration is already present (A, B). In order to limit dimensional alterations a socket grafting approach was chosen. The root was removed by a flapless low-trauma tooth extraction technique and the socket was grafted using Bio-Oss collagen (Geistlich Pharma, Wohlhusen, Switzerland) (C). A free gingival graft was harvested from the palate, carefully adapted and sutured (D). After 4 months of healing the grafted site revealed pleasing soft tissue conditions (E, F) and a partially preserved former extraction socket (G, H). The site allowed correct restoration driven implant placement (I, J) including subsequent contour augmentation.

vertical bone loss of the facial bone wall of, on average 2.6 mm after a 12-week healing period (12). Recent animal studies evaluated the effect on facial bone wall resorption of either a new nano-topography at the implant surface or microgrooves at the implant neck. Both studies revealed that neither the modified surface topography nor the implant design had a significant effect in limiting the facial bone wall resorption in immediate implant placement protocols (3, 92). Root-shaped implant designs have been proposed to reduce the gap between the implant surface and the former socket walls and thus to prevent bone loss. In contrast, wide root-shaped implants occupying most of the socket caused more pronounced alveolar bone resorption (24). In addition to immediate implant placement, simultaneous contour augmentation using deproteinized bovine bone mineral particles was performed in an experimental study. After 3 months of healing the buccal bone was not maintained but showed an average resorption of 2.3 mm (37).

Two recent clinical studies involving consecutive cone beam computed tomography at implant placement and after 1 year confirmed that significant mid-facial vertical bone resorption occurred in immediate implant cases (75, 89). Recent systematic reviews demonstrated that predictable results are difficult to obtain and that these techniques show an increased risk of significant mucosal recession if this approach is not applied with strict inclusion criteria (29, 33, 57). Following immediate implant placement, mid-facial recession exceeding 1 mm occurs in 9–41% of sites after 1–3 years (28). Other surgical factors, such as the use of a flapless technique, immediate provisional restorations, the applications of soft-tissue grafts or the use of implant-abutment connections with a platform-switching concept are still controversial because there is still no clear evidence for their efficacy (94). These need to be further investigated in well-designed clinical trials.

Clinical recommendations

In general, preservation of an extraction socket is indicated if immediate or early implant placement is not feasible due to patient- or site-specific indications. Patient-specific indications for ridge preservation techniques are (i) too young (age < 20 years) and (ii) treatment postponed for medical, financial or social reasons. Site-specific indications are related to the severity of the bone defect at the extraction site. Extensive defects require partial bone healing in order to later achieve sufficient primary stability of the implant in a correct 3D implant position. Sites associated with extensive soft tissue defects may require soft tissue grafting in order to improve keratinization and/or soft tissue volume prior to implant placement.

Maintenance of the root until the start of implant treatment is an easy and economical approach, but can only be recommended for roots without an acute or chronic inflammation, decay or a longitudinal fracture. Soft tissue closure of the extraction socket combined with the use of biomaterials with a low substitution rate is advisable, as this seems to retain the tissue volume at the site (13, 34, 49, 86, 93, 95).

Immediate implant placement does not prevent bone resorption *per se* and should only be used in sites where post-extraction bone modeling is expected to be minimal, such as with a thick bone wall phenotype (> 1 mm) and thick gingival biotype, as recommended by the 2013 International Team for Implantology (ITI) consensus conference (67). The facial bone wall of a former extraction socket can be maintained with an immediate implant placement protocol if strict patient inclusion criteria and appropriate techniques are applied (32, 63). If ideal conditions are not present, other implant timing protocols are preferred to achieve predictable esthetic outcomes (67, 94).

Conclusions

The dimensional bone and soft tissue alterations following tooth extraction in the anterior maxilla have a significant impact on the esthetic outcome of implant-supported restorations. Research has shown that significant bone modeling activities occur during the first 2 weeks of healing. Bone modeling in single extraction sites is mainly localized to the central aspect of the facial bone wall, whereas proximal aspects are well maintained by the periodontal ligaments of the adjacent teeth. The extent of flapless post-extraction bone modeling depends on the facial bone wall thickness. Whereas thin bone wall phenotypes (< 1 mm) often show a progressive bone resorption pattern with extensive vertical loss of the former socket wall, thick bone wall phenotypes (> 1 mm) show only limited resorption rates. Regarding dimensional soft tissue alterations, the facial soft tissue thickness does not necessarily correlate with the underlying bone wall dimensions. For thin bone wall phenotypes, extraction leads to spontaneous soft tissue thickening by a factor of seven, while no significant changes are seen for thick bone wall phenotypes. Finally, soft tissue thickening in thin bone wall phenotypes may mask the true extent of the underlying defect, which may mislead the clinician during the clinical examination. Neither ridge preservation techniques nor immediate implant placement prevents physiological bone modeling activity after tooth extraction. Therefore, tooth extraction should be performed with the understanding that ridge reduction will follow, and further clinical steps should be considered to compensate for such changes when considering replacement of the extracted tooth with an implant-supported restoration.

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