

# Alveolar Bone Preservation. Biological Basis and Techniques

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**Abstract** Tooth extraction or tooth loss can often result in both alveolar ridge resorption and soft tissue collapse. Preservation of bone volume and soft tissue height at the time of tooth extraction is an important procedure that can facilitate various treatment approaches specially implant placement and ensure that proper restorative goals are met. Proper management of extraction sites at the time of tooth extraction can reduce or eliminate the future need for advanced ridge augmentation procedures prior to implant placement. In addition, poor extraction site management may lead to esthetic and functional prosthetic complications.

**Keywords:** *alveolar bone, tooth*

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jaws, the thickness of the alveolar bone ridge is compromised earlier than its height [16].

## 1. Introduction

Alveolar ridge volume reduction is a direct consequence of tooth loss. [1,2] Such dimensional change occurs mainly at the expense of bone remodeling. [3,4] The limited amount of remaining bone volume may compromise the functional and esthetic rehabilitation of the edentulous span. Non extraction causes of alveolar bone loss include denture induced atrophy, trauma, periodontal disease, congenital alveolar defects, and tumor resection [5].

In an attempt to minimize post-extraction dimensional changes, clinicians are using alveolar ridge preservation (ARP) techniques immediately after tooth extraction. [6,7] A variety of surgical approaches and biomaterials have been proposed, including the use of autologous bone, allografts, xenografts, alloplastic materials, barrier membranes and growth factors. [8,9]

Although ARP has been investigated and yet debated, a consensus on the ideal clinical protocol has not been reached. [10,11,12,13] This limitation may be a result of the fact that there are a number of local and systemic variables that may affect the clinical outcomes, as well as that there are marked methodological differences among most published studies.

Ridge atrophy after tooth loss has been shown to follow certain patterns. In the maxilla, the labial wall of the alveolar socket tends to resorb more rapidly after dental extraction and the ridge gradually becomes represented by the previous palatal wall (centripetal resorption). [14] In the mandible, however, the lingual wall tends to resorb before the buccal (centrifugal resorption). This discrepancy in the resorption pattern frequently compromises the sagittal and axial intermaxillary relationship. [15] In both

## 2. Biology of Bone Loss after Extraction

The events that occur in a healing extraction socket have been identified histologically in both animals and humans. Five stages of healing in human extraction sockets have been described (Figure 1). [14] In the first stage a clot forms from the coagulation of red and white blood cells. The second stage involves the replacement of the clot by granulation tissue over a 4 to 5 day period. The third stage involves the replacement of the granulation tissue by connective tissue over a 14 to 16 day period. The connective tissue contains spindle shaped fibroblasts, collagen, and ground substance. In the fourth stage, calcification of osteoid takes place at the base of the socket. Early osteoid is seen at the base of the socket at 7 to 10 days, while it takes 6 weeks for bone trabeculae to fill the socket. In the fifth stage, epithelial closure of the socket is completed during a 24 to 35 day period following extraction. After 5 to 10 weeks of healing, substantial bone fill has taken place in the socket. [15] After 8 weeks, osteogenic activity begins to slow, and by 16 weeks bone fill is complete with relatively little osteogenic activity. [16]

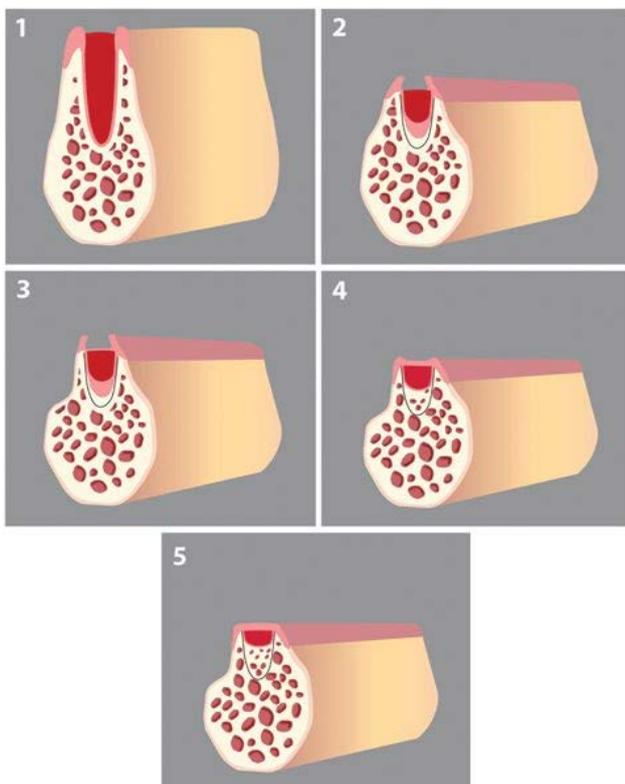
In combination with the healing events that are taking place within the extraction socket, gross morphologic changes are taking place in both the bone and overlying mucosa. Many different methods of analyzing morphological changes at extraction sockets have been described, including cephalometric measurements, study cast measurements, subtraction radiography, and direct measurement of the ridge. [17]

Most of the literature suggests that the loss of alveolar ridge following tooth extraction is greater in the horizontal dimension compared to the vertical dimension. Approximately 5 to 7 mm of horizontal or buccal-lingual ridge reduction can occur during a 6 to 12 month period. In a 12 month prospective study, Schropp and coworkers analyzed 46 premolar and molar extraction sockets from 46 patients and found a 50% loss in ridge with an average 6.1 mm of horizontal loss. Two thirds of this loss of bone volume occurred within the first 3 months, and changes were slightly greater in the molar region compared to the premolar area. [4]

Likewise, Lekovic and coworkers described an average horizontal ridge loss of 4.5 mm six months following tooth extraction. [18] In another study, Iasella and coworkers described an average horizontal ridge loss of 3.6 mm six months following tooth extraction. [7] Corresponding reductions in vertical ridge height ranging from 2.5 to 4.5 mm have also been noted in another study. [19]

Several studies investigated the vertical height changes after extraction. Lekovic and coworkers demonstrated a loss in vertical height of 1.5 mm after 6 months, [18] Schropp and coworkers described a loss of 0.7 mm in height after 12 months, [4] Also, Iasella and coworkers described a loss of 0.9 mm in height after 6 months. [7]

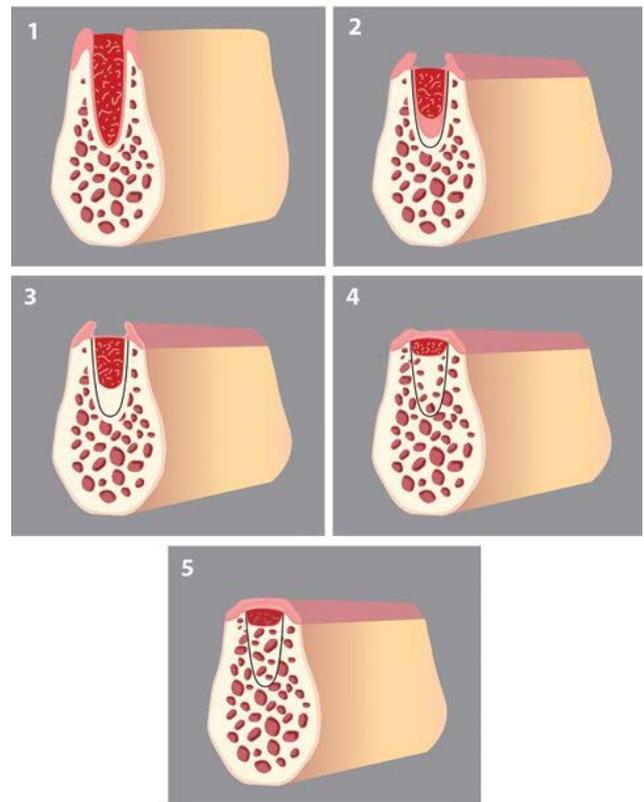
In addition to differences in dimensional changes that exist among vectors, others studies have suggested that the amount of ridge contraction varies within the socket itself. In the apical and middle portions of the socket site, minor dimensional alterations occurred, while in the coronal portion of the ridge the reduction of the hard tissue volume was much more significant. [20]



**Figure 1.** The five stages of extraction socket healing

### 3. Extraction Socket Healing with Socket Preservation

Many studies have looked at the results of ridge dimension following tooth extraction after the use of an intra-socket graft with either an absorbable or non-absorbable membrane compared to extraction alone. Iasella and coworkers analyzed ridge width and ridge height in non-molar extraction sockets when freeze dried bone allograft and a collagen membrane were used after tooth extraction, and compared these dimensions to extraction alone (Figure 2). They found that the sockets that were preserved lost 1.6 mm less ridge width and 2.2 mm less ridge height. Maxillary sites lost more than mandibular sites, and most ridge resorption occurred on the buccal aspect of the ridge. In addition, this group noticed approximately 15% more bone in the sockets that were preserved. [7] Lekovic and coworkers compared the use of a bioabsorbable membrane over extraction sockets to extraction sockets alone and found that the preserved sites lost 0.38 mm of ridge height and 1.3mm of ridge width as compared to extraction sites alone, which lost 1.5 mm of ridge height and 4.56 mm of ridge width. [18]



**Figure 2.** The five stages of extraction socket healing modified with socket preservation techniques

The findings from these studies indicated that a greater amount of socket resorption can be expected if a graft is not used and that sockets can be better preserved with the use of a graft. The question becomes, what is happening within the socket? Is the socket graft preventing ridge collapse or providing additional bone to compensate for the natural bony resorption process? Studies by Araujo

and Lindhe answered this question. The authors looked at the differences in healing of extraction sockets grafted with xenograft collagen versus no graft. The authors found that the presence of a graft failed to inhibit the processes of remodeling that took place in the socket walls following tooth extraction. However, the socket grafts acted as scaffolds and promoted new bone formation, particularly in the cortical region of the extraction sites. Because of this, the bony dimensions of the ridge were better maintained, which means better ridge profile when compared to sockets that were not grafted. The authors concluded that “the placement of a biomaterial in an extraction socket may promote bone modeling and compensate, at least temporarily, for marginal ridge contraction.” [20]

## 4. Preoperative Evaluation of Alveolar Ridge

Presurgical radiographic evaluation aims at obtaining measurements of bone dimensions and locating important anatomical landmarks, such as the maxillary sinus and the inferior alveolar nerve. [21] Various radiographic approaches, such as panoramic, periapical, occlusal, cephalometric, and tomographic radiographs have been used for assessment of bone dimensions. [22] However, two dimensional assessment was found to provide little information of bone thickness at different points of the alveolar ridge. [23] Three dimensional radiographic analysis of alveolar ridge has become popular. It is especially valuable in cases of significant ridge atrophy, or for reconstructing long edentulous segments. Precise interpretation of the ridge morphology can be obtained from high resolution or helical CT scanners with specialized software for guiding dental implant placement. [24] Furthermore, CT guided Stereolithographic templates, constructed based on the CT three dimensional data, have successfully been used as intraoperative guides for drilling and implant placement. [25,26,27].

## 5. Classifications of Alveolar Ridge

### A. In 1963, Atwood described 6 classes of alveolar ridge atrophy [28]

1. Pre extraction normal bone.
2. Post extraction normal bone: after extraction and before resorption started.
3. High, well rounded, adequate in height and width.
4. Knife edge, adequate height, inadequate width.
5. Low, well rounded, inadequate height and Width.
6. Depressed ridge.

### B. In 2004, Juodzbalys and Raustia, using panoramic x-ray, computerized tomography, and ridge mapping calipers classified alveolar ridge atrophy into 3 types [29]

Type I: Alveolar height is  $\geq 10$  mm and width is  $\geq 6$  mm and the vertical defect in the anterior region is  $\leq 3$  mm, which is optimal for implant placement.

Type IIA: The height is  $\geq 10$  mm and the width is 4-5 mm: narrow edentulous jaw dental segment

Type IIB: The height is 4-9 mm and the width is  $\geq 6$  mm.

Type IIC: The height is 4-9 mm and the width is 4-5 mm.

Type IID: The height is  $\geq 10$  mm and the width is  $\geq 6$  mm, the vertical cosmetic defect in an anterior region is  $> 3$  mm from the crest of the alveolar bone to the necks of adjacent teeth.

Type III: The height is  $< 4$  mm and the width is  $< 4$  mm (too shallow and too narrow for implantation).

### C. According to its density, alveolar bone has been classified into 4 types [30]

D-1 bone: Dense compacta; almost entirely composed of cortical bone, it is found in the anterior mandible, and this can withstand substantial loads because of its highly mineralized matrix.

D-2 bone: Porous compacta and coarse trabecular bone; it is commonly located in the posterior mandible and sometimes in anterior maxilla.

D-3 bone: Porous compacta and fine trabecular bone; found primarily in the anterior maxilla, it is more fragile than D1 and D2, and its bearing ability to load is reduced.

D-4 bone: Fine trabecular bone; most commonly found in long term edentulous posterior maxilla, it is characterized by extremely thin cortical bone and reduced density of cancellous bone; it is least suitable for implant placement and has failure rates as high as 35%.

## 6. Classification of Extraction Sockets

Since not all extraction sites are the same, Salama and Salama [31] as well as Elian et al [32] suggested extraction site classification schemes that were meant to be utilized in developing site specific treatment designs based on gingival margin level as well as the presence or absence of the labial and interproximal bone surrounding the compromised tooth to be extracted.

Tarnow et al [33] and Salama et al [34] demonstrated the direct relationship of the position of the interproximal bone surrounding a tooth or implant, respectively, to the location and shape of the overlying papilla. Where deficiencies existed in any of the criteria listed above, they would be classified as Type II or Type III sites, depending on the severity. [35] For such compromised sites, surgical augmentation protocols [36,37] and/or orthodontic site development [31] would be required to augment and reconstruct the lost hard and soft tissues prior to or at the time of implant placement. [38,39,40,41] However, whenever the extraction socket is not compromised with an esthetically acceptable mid facial gingival margin position and a completely intact labial plate and interproximal bone levels a Type I classification is rendered, demanding an emphasis on hard and soft tissue preservation protocols.

### A. Socket Classification by Salama and Salama. 1993 [31]

#### Type 1 extraction site

The Type 1 site is an incipient defect environment with a good regenerative potential and an acceptable esthetic prognosis as follows:

1. The environment is dominated by the four wall socket or the incipient three wall dehiscence type defect (5 mm or less in the apicocoronal direction). The osseous crests lie in the coronal third of the root to be extracted.

2. Adequate bone is available (i.e. 4 to 6 mm) beyond the apex for initial stabilization of an implant
3. Osseous crestal topography is harmonious, permitting an acceptable discrepancy between the head of the fixture, in the extraction socket, and the necks of the adjacent teeth. Usually a 3 to 5 mm offset is best, because it allows an optimal emergence profile of the restoration from the fixture.
4. The labial plate of bone is adequate, and recession on the tooth to be extracted is manageable, or where esthetics is not paramount (i.e., in a patient with a low smile line or in posterior quadrants).

Type 1 extraction sites, such as the ones exhibited about fractured roots, are best suited for immediate implant placement utilizing the principles of guided tissue regeneration (GTR). The critical requirement of initial stabilization is most readily achievable at these sites. In addition, although the volume of the socket can be large, the potential for regeneration in that environment is also great

#### **Type 2 extraction site**

Type 2 site is a moderately compromised regenerative and esthetic environment:

1. A moderate defect environment is predominant, and it extends through the middle third of the root; this includes dehiscence of greater than 5 mm.
2. The discrepancy between the osseous crests of the remaining socket and the necks of adjacent teeth is substantial.
3. Recession is significant and loss of the labial plate of bone is moderate. This is especially critical in the anterior region of the mouth in a patient with a high smile line.

#### **Type 3 extraction site**

Type 3 site is a severely compromised environment in which immediate implant placement is not an option:

1. Vertical and buccolingual dimensions of bone are inadequate for placement and stabilization of immediate implants.
2. Recession is present and loss of the labial plate of bone is severe.
3. Severe circumferential and angular defects are present.

### **B. Socket Classification by Elian et al, 2000. [32]**

Type I socket: Soft tissue and buccal plate of bone present which is ideal for immediate implant placement. If buccal plate of bone is more than 2mm and implant placement is not immediate, grafting may not be necessary.

Type II socket: Soft tissue is present but buccal plate of bone is missing. Bone grafting of socket is necessary with possible need for cell occlusive membrane. Delayed placement of implant may be recommended especially in esthetic areas.

Type III socket: Both soft tissue and buccal plate of bone are missing. Ridge augmentation procedures including bone grafting with space maintaining membranes are necessary and delayed placement of an implant is recommended.

### **C. Socket Classification by Edgard El Chaar et al 2016. [42]**

#### **Grade I**

Grade I sockets are the most ideal. Following tooth extraction, a socket that has an intact buccal plate, adequate interproximal bone, and satisfactory apical topography will fall into this category. In this

classification, an intact buccal plate is defined as having no fissures or dehiscences and less than 25% loss of height (Figure 3 & Figure 4). This percentage of buccal plate loss was selected as the cut-off based on the average root length of single-rooted teeth, which is 14.2 mm, [43] and the amount of buccal plate that can be reliably regenerated during immediate implant placement. Adequate apical topography is defined as enough bone present apical to the extraction site to allow for engagement of 3 mm to 4 mm of a properly positioned immediate dental implant (Figure 2). [44,45] Adequate interproximal bone is defined as no or mild (up to 2 mm) periodontal bone loss on the adjacent teeth as to allow for support of the interproximal soft tissue and to enable placement of the platform of an immediate implant in the proper apical-coronal position relative to the adjacent teeth while still being bordered by bony walls on the mesial and distal aspects (Figure 5). [46]

Grade I extraction sockets are treated with immediate implant placement with or without provisionalization depending on implant stability and the remaining gap between the implant and socket walls to be grafted.

#### **Grade II**

Grade II sockets are differentiated from Grade I by the amount and quality of the remaining buccal plate. A Grade II socket has a fissure, dehiscence, or deficiency of the buccal plate totaling a 25% to 50% loss. Like Grade I sockets, they have adequate interproximal bone and apical topography (Figure 3, Figure 4, & Figure 5).

For a patient with a thick biotype, an immediate implant can be placed in a Grade II extraction socket. The implant should not be temporized, and the remaining defect surrounding the implant should be grafted and contained by a barrier membrane. For a patient with a thin biotype, delayed implant placement with site preservation is recommended. If the extraction site is located in the maxilla, the rotated pedicle palatal connective tissue flap technique should be used to enhance the thin soft tissue profile and to allow for a more esthetic outcome following delayed implant placement. [47] In this case, the location of the extraction site must be considered because if it is in the maxilla, keratinized tissue can easily be borrowed through rotated pedicle grafting to increase tissue. [48] If the extraction socket is in the mandible, site preservation with delayed implant placement is recommended. This more conservative approach is recommended because of the characteristics of a thin biotype and its susceptibility to recession during surgical manipulation and mechanical injury. [47,49]

Discrepancies in the mucogingival line that may result from primary closure in the area of an extraction socket or any noted deficiencies in the soft tissue can be corrected during implant uncovering.

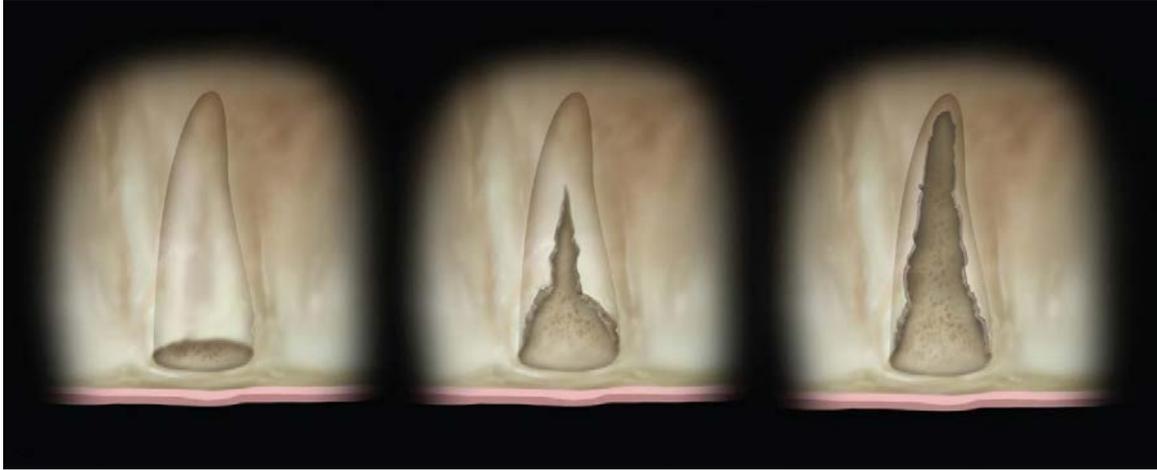
#### **Grade III**

Grade III sockets are the most deficient and include any socket with inadequate apical topography, insufficient interproximal bone, or more than 50% loss of buccal plate. Inadequate apical topography is defined as not enough bone present apical to the extraction site to allow for implant placement and may be the result of bone loss caused by periapical lesions or concavities due to existing anatomy of the alveolus (Figure 3 & Figure 4). Insufficient interproximal bone is defined as moderate to severe

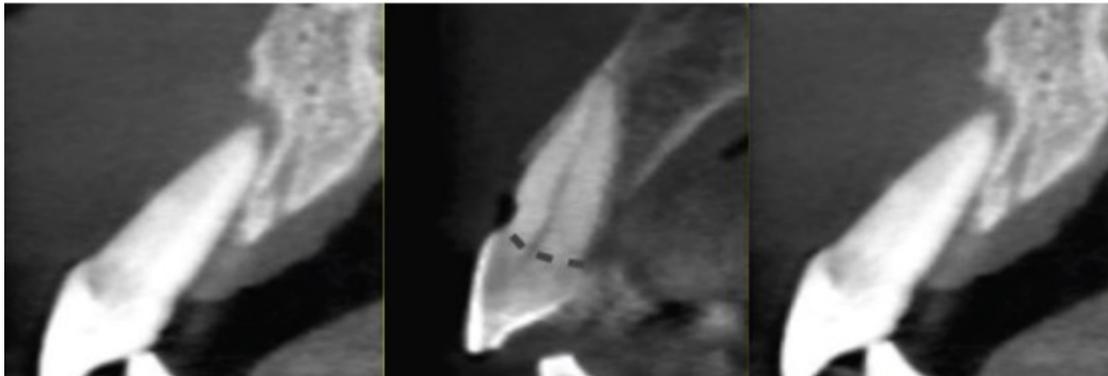
periodontal bone loss greater than 2 mm on one or both of the adjacent teeth.

Grade III sockets are further divided into those with inadequate apical topography and those that have interproximal bone loss with or without buccal plate loss. If the socket is Grade III due to inadequate apical topography, the extraction socket should be treated with a ridge augmentation type of guided bone regeneration (GBR) to correct the inadequate apical topography and delayed implant placement.

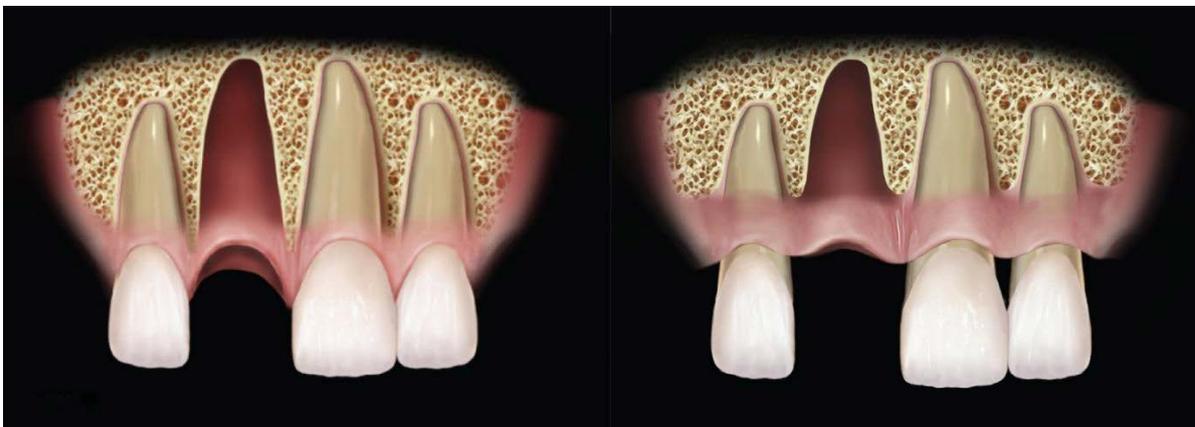
In a Grade III extraction socket with adequate apical topography and interproximal bone loss regardless of biotype, the protocol will be the same as for a Grade II with thin biotype which includes, delayed implant placement with site preservation. If the extraction site is located in the maxilla, the rotated pedicle palatal connective tissue flap technique should be used; if the extraction socket is located in the mandible, site preservation with delayed implant placement is recommended.



**Figure 3.** (Left) Grade I socket with an intact buccal plate demonstrating less than 25% bone loss; (Center) Grade II socket showing fissure, dehiscence, and approximately 50% buccal plate loss; (Right) Grade III socket with more than 50% buccal plate loss.



**Figure 4.** Sagittal cross sections of CBCT images depicting Grade I (Left), Grade II (Center), and Grade III (Right) sockets. Note the level of the buccal plate relative to the cemento-enamel junction that is elucidated by this cross-cut



**Figure 5.** (Left) Example of adequate interproximal bone. The periodontium is healthy, and the bony peeks on either side of the extraction socket are aiding in supporting the interproximal papilla. (Right) A mildly reduced periodontium. Interproximal bone is present; there is enough bone to support full papilla in the embrasure spaces of the natural dentition.

## 7. Bone Graft Materials Used in Socket Preservation

The purpose of extraction socket preservation is to preserve the original alveolar dimensional contours by limiting the natural post extraction resorptive process. [50] There are many types of regenerative material available, and choosing the correct material should be case specific. Selection of the type of regenerative material and/or membrane used during socket preservation depends largely upon alveolar bone defect morphology. A general rule of thumb is that the less space maintaining a defect is, the greater the osteogenic and space maintaining potential your graft material should have. For example, Fugazzotto suggested that in the presence of a space maintaining osseous defect, with intact cortical plates, the graft material should be covered by an absorbable membrane. [51] However, he added that when grafting non space maintaining defects, generally, the use of titanium reinforced membranes over particulate graft material would have superior results compared to bioabsorbable membranes. [51]

In order to choose the appropriate graft material, a complete evaluation of the socket's space maintaining ability must be performed prior to choosing the correct graft and membrane materials. A number of bone grafting materials are available for use in site preservation. These fall into one of four categories: autogenous bone grafts, allogeneous bone grafts, xenogeneous bone grafts, and alloplasts. Depending on which of these is used, the process can be osteoconductive, osteopromoting, osteoinductive, or one of osteogenesis.

Currently, stem cell research is being conducted on the use of stem cells for bone grafting. These stem cells could be autologous or allogeneous in origin. This technique may result in the availability of stem cell based bone grafts for localized ridge preservation as well as ridge augmentation and craniofacial regeneration in the future. [52,53]

## 8. Guided Tissue Regeneration Used in Socket Preservation

Guided tissue regeneration (GTR) is a term that describes not only alveolar bone regeneration but also the regeneration of the periodontium, including cementum and periodontal ligament; whereas the term guided bone regeneration (GBR) applies only to bone regeneration. [54] The model of guided bone regeneration was first used in 1959 in a canine spinal fusion [55] later it was attempted in alveolar reconstruction. [56,57] Both techniques share the same principles of using a barrier membrane to maintain the space underneath and to prevent soft tissue in growth that inhibits bone regeneration. [58]

A wide range of tissue compatible, resorbable and non resorbable, membrane materials have been used. Non resorbable membranes, such as expanded polytetrafluoroethylene (ePTFE), [59] titanium reinforced polytetrafluoroethylene, [60] and titanium mesh, have proved to maximize the graft space volume and given promising results. [61,62] However, the technique has a significant rate of complications, reported to be 20% -50%,

including infection, tissue inflammation, and healing deficiency. [63,64]

Complications associated with the use of non resorbable membranes highlight the need to use bioresorbable membranes having different chemical and biologic properties. [62,64] Major concerns with the use of resorbable membranes include that they are collapsible and lack mechanical stability, requiring the use of a graft material to maintain the space underneath. [65] Cross linked collagen based membranes of porcine origin may bring forth an immune response, [66] and non-cross linked membranes have a high degradation rate. [67]

Synthetic resorbable membranes, such as polyglycolic and trimethylene carbonate are better in this regard, [68,69] although foreign body reaction may also be initiated by the degrading products of these materials. [70] In other studies, hydrogel made of polyethylene glycol was successfully used as barrier membrane. [71]

## 9. Biological Mediators Used in Socket Preservation

Using growth factors has received more attention for treatment of atrophic ridges. Bone morphogenetic proteins (BMPs), which are member of transforming growth factor superfamily, have the ability to stimulate the osteogenic cascade, [72] with BMP-2 and -7 showing very promising results for intraoral applications. [73]

BMP-2 was used safely for intraoral ridge preservation [74,75] and sinus lift augmentation. [76] Platelet derived growth factor and insulin like growth factor 1 were effectively used intraorally with expanded polytetrafluoroethylene (ePTFE), [77] bone blocks, [78] and tricalcium phosphate. [79] Addition of platelet rich plasma to the graft material proved to be successful to accelerate bone formation. [80]

## 10. Treatment of Atrophic Ridge

### I-Correction of vertical atrophy

#### 1. Sinus floor elevation (sinus lift with bone grafting)

This procedure is used to increase the height of atrophied maxillary ridge, typically limited to the molar and premolar regions. The sinus should show no sign of pathology preoperatively. [81] Sinus lift grafting and implant placement can be done in either 1 or 2 steps, depending on the amount of available bone. Simultaneous grafting and implant placement can be done if there is a height of 5 mm intact alveolar bone to provide adequate mechanical support during implant healing. [81] if the available host bone height is 5 mm, a healing period of 4-6 months should be allowed for graft healing before implant placement. [82]

Subantral augmentation can be done using autogenous bone from intra and extra oral sites. [83,84,85] However, donor site morbidity and the need for general anesthesia have induced the search for non-autogenous sources. [86]

Demineralized freeze dried cortical bone has been tried as substitute for autogenous grafts in sinus lift. [87] However, this type of allograft has shown significant resorption. [88]

Alloplastic materials, such as hydroxyapatite, beta-tricalcium phosphate, [89] and BMPs and other bone specific growth factors, [90,91] as well as bovine bone xenografts, [92] have been used with promising results. Sinus floor grafting may be used with a barrier membrane, which has been reported to enhance implant success. [93] On the other hand, sinus augmentation may compromise sinus drainage through perforation of the sinus lining [94] and reduction of the size of maxillary antrum, leading to chronic sinusitis. [95] Sinus augmentation sometimes contributes to the development of sinus cysts. [96]

## 2. Distraction osteogenesis

Distraction osteogenesis (DO) is the process of new bone formation between bone segments that are gradually separated by incremental traction. [97] Craniofacial DO has been tested in experimental animals. [98] Clinically, it has been used for elongation of the mandible, [99,100] correction of mid face hypoplasia, [101] and reconstruction of defects of the mandible after tumor resection. [102,103] In alveolar ridge augmentation, DO has been tested both experimentally [104] and clinically. [101,105] This technique could improve the amount of both hard and soft tissue in cases of severe atrophy. [105,106] Alveolar DO has been used more frequently to increase alveolar bone height [105,107,108] than to increase its thickness. [107,108]

The technique is simple to perform with minimal trauma and does not require a donor site. Implants could be placed 4-8 weeks after surgery, a relatively short time compared with graft healing. [109] New bone created by distraction in some studies showed 24% mineralization at the end of active distraction and 78% at the end of the retention period, gradually maturing into stable lamellar bone. [105,110]

Distraction systems currently used for vertical DO of alveolar bone have 3 forms:

1. Extraosseous alveolar distraction [12,106,111,112] e.g. The track distractor by Martin (Tuttlingen, Germany)
2. Intraosseous alveolar distraction [101,113,114,115] e.g. Lead System (Leibinger).
3. Distraction implant [110,116]

Placement of implants into distraction regenerate has been carried out successfully. However, it typically required at least 3 surgical procedures: distraction device application, removal, and implant insertion. [110,117] The direction of vertical distraction is opposite to that of the occlusal forces, which may be the main reason for this problem. The main concern of the DO technique is the stability of the regenerate and its resorption rate. [105] Other complications include infection, wound dehiscence, bleeding, nerve injury, adjacent tooth damage, early or delayed consolidation, undesirable transport disk movement, and fracture of transport disk of bone owing to drilling, screwing, or fixation of the device itself. Another limitation of vertical alveolar distraction is the high incidence of relapse. [118]

## II-Correction of horizontal alveolar atrophy

Alveolar ridge widening before implant placement is indicated in cases of crest thickness of 4 mm. Several techniques have been described. [119] These include: -

### A-Acute horizontal widening

#### 1. Osteotome technique

This technique depends on the viscoelastic properties of the existing bone, and therefore it would be more

applicable in the maxilla, which has soft spongiosa that makes it more elastic. [80,120,121] An ultrathin osteotome, or a series of increasingly thicker osteotomes, is used to surgically split the 2 cortices. [107,122] This technique eliminates heat generation produced by drilling and conserves osseous tissue, improving bone density. [80] However, the use of excessive force in the buccal cortex of the mandible or extremely thin maxillary alveolus that doesn't have spongiosa may lead to unintended fractures of the buccal cortex.

### 2. Ridge widening using punch-tip pilots or implant analog

This procedure expands the alveolar ridge by using successive wedging of smooth surface implant analog that is inserted in between the 2 surgically split cortices and driven in by circular motion. [123] Another way of expanding the alveolus is by successive insertion of 3 increasing diameter punch-tip pilots. [124] Finally, when the desired size is attained, the implant is tapped into place and covered with guided bone regeneration membrane. [123,124]

### 3. Segmental split-ridge procedure

This procedure involves the creation of a crestal groove along the edentulous segment, ending within 2 mm of the line angle of the bordering teeth. Then, 2 vertical monocortical osteotomies are carried out at each end and the buccal cortex is separated with the use of a chisel. The implant bed is prepared through the osteotomy and in the basal bone with traditional drills. Once the implants are in place, the facial and palatal plates of bone are compressed back and secured with thin ligature wire passing through both plates. The remaining space is then packed with demineralized freeze-dried bone allograft mixed with the patient's own blood. [125]

### 4. Ridge splitting and anterior maxillary osteoplasty with immediate implant placement

In this procedure, the anterior maxilla is split by horseshoe osteotomy extending from the crest of alveolar ridge into the floor of nose. The buccal cortex is then separated from the palatal cortex and advanced to increase ridge thickness. [126] In another technique, the whole length of the edentulous alveolar maxillary ridge is split. [119] In both cases, the apical part of the implant bed is prepared and implants are immediately inserted. Bone grafts are packed into the spaces in between the implants and left to heal. [119,127]

### B- Le Fort I osteotomy

Classic Le Fort I maxillary osteotomy is a versatile procedure in oral and maxillofacial surgery, but it has been rarely described for correction of malocclusion and vertical maxillary deficiency because of instability and tendency to major relapse. [128,129] In contrast, the procedure has shown more stable results in maxillary setback and impaction movements. [130] Relapse could be eliminated either by using mini plates instead of wire fixation [131] or by insertion of bone grafting material in the gap between the lowered maxilla and the skull. [132] Modified osteotomy designs that retain bony contact during the healing process have also been tried successfully. [132,133]

### C- Horizontal gradual distraction

Transverse alveolar distraction devices include the following: -

### 1. Laster crest device

This device consists of two parallel metal arches; each has one horizontal plate and two vertical sharp blades that are inserted into the alveolar crest. The two horizontal plates are connected together by two sliding pins and two laterally positioned activation screws. Activation gradually separates the two arches, thereby expanding the alveolar crest. To install the device, a round bur is used to create a furrow on the alveolar crest. Then 2-10 mm vertical cuts are made on the buccal cortex and the buccal plate is greenstick fractured (without separation) with the use of an osteotome. The distractor is then tapped into place. After a 1 week latency period, distraction is started at a rate of 0.4 mm/day until the desired thickness is reached. [115]

### 2. Multidirectional osteodistraction device

This tooth-supported device can provide simultaneous vertical and horizontal distraction if needed. Bicortical bone segment is separated from the alveolar ridge by one horizontal and two vertical osteotomies. Then, intraosseous anchor abutments are inserted into the bone segment, anchored against the basal bone. Activation of the device results in controlled vertical and horizontal movement of the bone segment relative to the surrounding teeth onto which the device is anchored. [115]

### 3. Extension crest device

This device consists of two arms that are apically hinged together and crestally connected by a threaded pin that passes transversely through one arm to abut against the other. Activation of the screw pushes the crestal ends of 1 arm away from the other around the apical hinge. The device is installed vertically through the alveolar crest after splitting the buccal cortex from the lingual by two vertical osteotomies connected by a horizontal crestal osteotomy. The device can be used to gain immediate space in the highly viscoelastic maxillary bone or used as a traditional distractor with a rate of 1 mm/day in the mandible. [134]

### D- Tent-pole grafting technique

A novel approach has been introduced using dental implants, titanium screws, or cortical bone, to create a tenting effect of the periosteum and soft tissue and was shown to maintain graft volume. This approach was reported to be very successful in the treatment of severely atrophied mandibles and maxillas in combination with iliac crest bone grafting or human mineralized allograft. [135,136,137]

Titanium mesh with iliac crest graft was also reported to be successful in the treatment of atrophied ridges but with a high rate of mesh exposure that may compromise graft volume. [138]

## 11. Alveolar socket preservation (ASP)

Different techniques for alveolar socket preservation were used including: -

### A. The use of biomaterials Graft

For ASP bone grafts or barriers (membranes) are used separately or in many cases they are used together. [7,18,69,136,137,138,139]

The possible beneficial effect of using grafting procedures or guided bone regeneration to preserve the

ridge after tooth extraction has been tested in both animal and human studies. [20,140] The socket is immediately filled after tooth extraction with bone graft [141].

The application of regenerative biomaterials, such as bone autografts, allografts, guided tissue regeneration procedures, xenografts and most recently, growth factors, has been evaluated with varying degrees of success to maintain the anatomical dimensions of the alveolar ridge after tooth extraction. Studies suggested that the placement of the xenograft counteracted the ridge contraction in the buccolingual dimension, yet grafting with autogenous bone did not significantly alter the ridge resorptive process. [142]

Another systematic review evaluated the efficacy of these therapies in non-molar alveolar regions suggesting that these techniques may not prevent the physiological resorptive bone processes after tooth extraction, although they may aid in reducing the resulting bone dimensional changes. [142]

Vignoletti et al reported in a systemic review that a higher level of evidence was obtained with the studies of barriers; however, their statistical significance gives rise to doubts, because the barriers alone produced better clinical results than grafts with barriers or grafts alone. It could be argued that the protective, space making effect of the barriers on the blood clot inside the socket and on the remaining bone walls outside the socket is responsible; i.e., the barrier, acting as a shield, could enhance the physiologic healing process, minimizing bone loss and maximizing bone repair, with a resulting net effect of improvement versus untreated extraction sockets in terms of bone height and width. [143]

### B. Flap Management

Many studies elevated buccal and lingual mucoperiosteal flaps to perform the tooth extraction and achieved primary closure. Flapless extraction of the teeth was performed in several studies with another studies aiming to primary closure through a soft tissue autograft. [7,18,69,136,137,138,139].

It could be argued that socket preservation techniques are effective regardless of whether primary flap closure is achieved; it could be speculated that the influence of releasing incisions on wound healing of both soft and hard tissues would at least slightly modify the clinical outcome.

The possible beneficial effect of a flapless surgery during tooth extraction for limiting the resorptive process of the alveolar crest has been investigated in preclinical models by comparing the outcomes with a flapped conventional surgery. Although some studies have shown slightly less pronounced bone remodelling of the alveolar ridge after flapless tooth extraction, [144,145] other studies have failed to encounter significant differences between flapped and flapless tooth extractions. [3,140]

### C. The use of implant

Implants could be either placed after extraction or at the time of extraction. Several studies [7,147,151] reported that implant placement in the previous sockets were successful, but no differences between the ASP and untreated sites were revealed. The use of endosseous implants for partial or complete dental restoration has gained popularity in the past few decades, with reliable long term stability. [152] Functional loading of osseointegrated implants has been shown to substantially reduce bone loss and even promote bone growth in edentulous jaw segments. [153]

Several studies on implant placement after tooth extraction reported the placement of implants after 3 and >7 months without providing any details on further soft or hard tissues augmentation procedures. [7,136,138,147,151] Serino et al. reported the placement of dental implants after 3 and 6 months of healing respectively, specifying that all implants achieved good primary stability in both test and control groups. [154] In one study implants were inserted after 4 months of healing and statistically significant differences were reported in favor of the test group 1 with absorbable collagen sponge and 1.50 mg/ml recombinant human bone morphogenetic protein-2 (ACS+1.50 mg/ml rhBMP-2) when compared to test group 2 (ACS+0.75 mg/ml rhBMP-2) and the control treatment, in regards to the number of secondary augmentation surgeries needed, although no further details were provided in regards to the number and type of these procedures. In the test 1 sites, 56.25% demonstrated adequate bone volume for implant placement, whereas the corresponding figures in test 2 and control groups were 25% and 12.5% respectively. [69]

## 12. Factors Affecting Socket Preservation Technique Outcome

### A- Healing time

The optimal timing of reentry following ASP is determined by the implant insertion. Since the volume of the alveolar ridge is gradually decreasing, while the quality of the newly formed tissue is gradually increasing during the post extraction remodeling the implant placement could be considered as early as possible, but as late as necessary, in order to maintain alveolar ridge volume, as well as to achieve complete epithelial seal with some extent of osseous fill. The healing periods of the trials varied considerably from 1-9 months. [3,155]

### B-Antimicrobials

Improvement of clinical parameters was demonstrated as a result of regular rinsing with chlorhexidine following tooth extraction. In a study subjects were prescribed various types of antibiotics and instructed to rinse with chlorhexidine for 2 to 3 weeks, yet no conclusion could be drawn on the necessity or benefit of employment of antibiotics/antimicrobials following ASP. [156]

### C-Smoking

Smoking is associated with delayed socket healing and increased reduction in post extraction alveolar width. [157] Several studies were conducted included smokers and the half of the studies did not report on smoking as an exclusion factor, thus any conclusions about the impact of this well recognized risk factor for impaired healing are difficult to draw. [7,158]

### D-Periodontal treatment/health

Studies included patients whose periodontal treatment was carried out prior to the ASP. [18,151,150] ASP resulted in statistically significant difference between tests and controls in clinical and in histological parameters. [30] In addition, in the studies where periodontitis was present, but periodontal treatment was not reported, no statistically significant histological differences were demonstrated. [150,158,159] This suggests that treated periodontitis may not hinder the success of ASP.

## References

- [1] Van der Weijden F, Dell'Acqua F, Slot DE. Alveolar bone dimensional changes of post-extraction sockets in humans: a systematic review. *J Clin Periodontol* 2009; 36(12): 1048-1058.
- [2] Tan WL, Wong TL, Wong MC, Lang NP. A systematic review of post extraction alveolar hard and soft tissue dimensional changes in humans. *Clin Oral Implants Res* 2012; 23(suppl 5): 1-21.
- [3] Araújo MG, Lindhe J. Dimensional ridge alterations following tooth extraction: an experimental study in the dog. *J Clin Periodontol* 2005; 32(2): 212-218.
- [4] Schropp L, Wenzel A, Kostopoulos L, Karring T. Bone healing and soft tissue contour changes following single-tooth extraction: a clinical and radiographic 12 month prospective study. *Int J Periodontics Restorative Dent* 2003; 23(4): 313-323.
- [5] Barone A, Ricci M, Tonelli P, Santini S, Covani U. Tissue changes of extraction sockets in humans: a comparison of spontaneous healing vs. ridge preservation with secondary soft tissue healing (published online ahead of print July 12, 2012). *Clin Oral Implants Res* 2012.
- [6] Cardaropoli D, Tamagnone L, Roffredo A, Gaveglia L, Cardaropoli G. Socket preservation using bovine bone mineral and collagen membrane: a randomized controlled clinical trial with histologic analysis. *Int J Periodontics Restorative Dent* 2012; 32(4): 421-430.
- [7] Iasella JM, Greenwell H, Miller RL, et al. Ridge preservation with freeze dried bone allograft and a collagen membrane compared to extraction alone for implant site development: a clinical and histologic study in humans. *J Periodontol* 2003; 74(7): 990-999.
- [8] Chan HL, Lin GH, Fu JH, Wang HL. Alterations in bone quality after socket preservation with grafting materials: a systematic review. *Int J Oral Maxillofac Implants* 2013; 28(3): 710-720.
- [9] Darby I, Chen ST, Buser D. Ridge preservation techniques for implant therapy. *Int J Oral Maxillofac Implants* 2009; 24(suppl): 260-271.
- [10] Horowitz R, Holtzclaw D, Rosen PS. A review on alveolar ridge preservation following tooth extraction. *J Evid Based Dent Pract* 2012; 12(3 suppl): 149-160.
- [11] de Wijs FL, Cune MS. Immediate labial contour restoration for improved esthetic: a radiographic study on bone splitting in anterior single tooth replacement. *Int J Oral Maxillofac Implants* 1997; 12: 686-96.
- [12] Gaggi A, Rainer H, Chiari FM. Horizontal distraction of the anterior maxilla in combination with bilateral sinus lift operation preliminary report. *Int J Oral Maxillofac Surg* 2005; 34: 37-44.
- [13] Cawood JI, Howell RA. A classification of the edentulous jaws. *Int J Oral Maxillofac Surg* 1988; 17: 232-6.
- [14] Misch CE. *Contemporary Implant Dentistry*. Mosby Elsevier, 2005, ch 37.
- [15] Boyne PJ. Osseous repair of postextraction alveolus in man. *Oral*.
- [16] Evian CI, Rosenberg ES, Cosslet JG, Corn H. The osteogenic activity of bone removed from healing extraction sockets in human. *J Periodontol* 1982; 53: 81-85.
- [17] Chen S, Wilson T, Hammerle C. Immediate or early placement of implants following tooth extraction: review of biological basis, clinical procedures, and outcomes. *Int J Oral Maxillofac Implants* 2004; 19: 12-23.
- [18] Lekovic V, Camargo PM, Klokkevold PR, et al. Preservation of alveolar bone in extraction sockets using bioabsorbable membranes. *J Periodontol* 1998; 69: 1044-9.
- [19] Lam RV. Contour changes of the alveolar processes following extraction. *J Prosthet Dent* 1960; 10: 25-32.
- [20] Araújo MG, Lindhe J. Ridge alterations following tooth extraction with and without flap elevation: an experimental study in the dog. *Clin Oral Implants Res* 2009 Jun; 20(6): 545-9.
- [21] Erkut S, Uckan S. Alveolar distraction osteogenesis and implant placement in a severely resorbed maxilla: a clinical report. *J Prosthet Dent* 2006; 95: 340-3.
- [22] Petrikowski CG, Pharoah MJ, Schmitt A. Presurgical radiographic assessment for implants. *J Prosthet Dent* 1989; 61: 59-64.
- [23] Jacobs R, Adriansens A, Verstreken K, Quirynen M, Hermans R, van Steenberghe D. Predictability of reformatted computed tomography for preoperative planning of endosseous implants. *Dentomaxillofac Radiol* 1999; 28: 37-41.
- [24] van Assche N, van Steenberghe D, Guerrero ME, Hirsch E, Schutyser F, Quirynen M, Jacobs R. Accuracy of implant

- placement based on pre-surgical planning of three-dimensional cone beam images: a pilot study. *J Clin Periodontol* 2007; 34: 816-21.
- [25] Luka B, Brechtelsbauer D, Gellrich NC, König M. 2D and 3D CT reconstructions of the facial skeleton: an unnecessary option or a diagnostic pearl? *Int J Oral Maxillofac Surg* 1995; 24: 76-83.
- [26] Hussein MO, Elkarargy AA: Accuracy of Implant Placement Using Modified Mucosa- Supported Stereolithographic Surgical Guide. *Journal of Implant and Advanced Clinical Dentistry* 2013; 5: 7: 25-35.
- [27] Naitoh M, Katsumata A, Kubota Y, Arijii E. Assessment of three dimensional x-ray images: reconstruction from conventional tomograms, compact computerized tomography images, and multi slice helical computerized tomography images. *J Oral Implantol* 2005; 31: 234-41.
- [28] Atwood DA. Postextraction changes in the adult mandible as illustrated by microradiographs of midsagittal sections and serial cephalometric reontgenograms. *J Prothet Dent* 1963; 13: 810-24.
- [29] Juodzbalys G, Raustia AM. Accuracy of clinical and radiological classification of the jawbone anatomy for implantation a survey of 374 patients. *J Oral Implantol* 2004; 31: 30-9.
- [30] Jaffin RA, Berman CL. The excessive loss of Branemark fixtures in type IV bone: a 5-year analysis. *J Periodontol* 1991; 62: 2-4.
- [31] Salama H, Salama M. The role of orthodontic extrusive remodeling in the enhancement of soft and hard tissue profiles prior to implant placement: a systematic approach to the management of extraction site defects. *Int J Periodontics Restorative Dent.* 1993; 13(4): 312-333.
- [32] Elian N, Cho SC, Froum S, et al. A simplified socket classification and repair technique. *Pract Proced Aesthet Dent.* 2007; 19(2): 99-104.
- [33] Tarnow DP, Magner AW, Fletcher P. The effect of the distance from the contact point to the crest of bone on the presence or absence of the interproximal dental papilla. *J Periodontol.* 1992; 63(12): 995-996.
- [34] Salama H, Salama MA, Garber D, Adar P. The interproximal height of bone: a guidepost to predictable aesthetic strategies and soft tissue contours in anterior tooth replacement. *Pract Periodontics Aesthet Dent.* 1998; 10(9): 1131-1141.
- [35] Funato A, Salama MA, Ishikawa T, et al. Timing, positioning, and sequential staging in esthetic implant therapy: a four dimensional perspective. *Int J Periodontics Restorative Dent.* 2007; 27(4): 313-323.
- [36] Buser D, Ruskin J, Higginbottom F, et al. Osseointegration of titanium implants in bone regenerated in membrane-protected defects: a histologic study in the canine mandible. *Int J Oral Maxillofac Implants.* 1995; 10(6): 666-681.
- [37] Wang HL, Boyapati L. "PASS" principles for predictable bone regeneration. *Implant Dent.* 2006; 15(1): 8-17.
- [38] Buser D, Dula K, Belser UC, et al. Localized ridge augmentation using guided bone regeneration. II. Surgical procedure in the mandible. *Int J Periodontics Restorative Dent.* 1995; 15(1): 10-29.
- [39] Buser D, Dula K, Hess D, et al. Localized ridge augmentation with autografts and barrier membranes. *Periodontol* 2000. 1999; 19(1): 151-163.
- [40] Grunder U. Crestal ridge width changes when placing implants at the time of tooth extraction with and without soft tissue augmentation after a healing period of 6 months: report of 24 consecutive cases. *Int J Periodontics Restorative Dent.* 2011; 31(1): 9-17.
- [41] Kan JY, Rungcharassaeng K, Lozada JL, Zimmerman G. Facial gingival tissue stability following immediate placement and provisionalization of maxillary anterior single implants: a 2 to 8 year follow up. *Int J Oral Maxillofac Implants.* 2011; 26(1): 179-187.
- [42] Edgard El Chaar, Sarah Oshman, Pooria Fallah Abed. Single-Roofed Extraction Sockets: Classification and Treatment Protocol *Compend Contin Educ Dent.* 2016 Sep; 37(8): 537-541; quiz542
- [43] Wheeler RC. *A Textbook of Dental Anatomy and Physiology.* Philadelphia, PA: WB Saunders; 1950.
- [44] Nencovsky CE, Artzi Z, Moses O, Gelernter I. Healing of marginal defects at implants placed in fresh extraction sockets or after 4-6 weeks of healing. A comparative study. *Clin Oral Implants Res.* 2002; 13(4): 410-419.
- [45] Juodzbalys G. Instrument for extraction socket measurement in immediate implant installation. *Clin Oral Implants Res.* 2003; 14(2): 144-149.
- [46] Cooper LF, Raes F, Reside GJ, et al. Comparison of radiographic and clinical outcomes following immediate provisionalization of single-tooth dental implants placed in healed alveolar ridges and extraction sockets. *Int J Oral Maxillofac Implants.* 2010; 25(6): 1222-1232.
- [47] Kois JC, Vakay RT. Relationship of the periodontium to impression procedures. *Compend Contin Educ Dent.* 2000; 21(8): 684-690.
- [48] El Chaar ES. Soft tissue closure of grafted extraction sockets in the posterior maxilla: the rotated pedicle palatal connective tissue flap technique. *Implant Dent.* 2010; 19(5): 370-377.
- [49] Muller HP, Heinecke A, Schaller N, Eger T. Masticatory mucosa in subjects with different periodontal phenotypes. *J Clin Periodontol.* 2000; 27(9): 621-626.
- [50] Araújo MG, et al. The influence of Bio-Oss Collagen on healing of an extraction socket: an experimental study in the dog. *Int J Periodontics Restorative Dent* 2008 Apr; 28(2): 123-35.
- [51] Fugazzotto P. GBR using bovine bone matrix and resorbable and nonresorbable membranes. Part 1: Histologic results. *Int J Periodontics Restorative Dent* 2003; 23: 361-9.
- [52] Ueda M, Yamada Y, Ozawa R, Okazaki Y. Clinical case reports of injectable tissue-engineered bone for alveolar augmentation with simultaneous implant placement. *Int J Periodontics Restorative Dent* 2005; 25(2): 129-37.
- [53] Hibi H, Yamada Y, Ueda M, Endo Y. Alveolar cleft osteoplasty using tissue engineered osteogenic material. *Int J Oral Maxillofac Surg* 2006; 35: 551-5.
- [54] McAllister BS, Haghghat K. Bone augmentation techniques. *J Periodontol* 2007; 78: 377-96.
- [55] Hurley LA, Stinchfield FE, Bassett AL, Lyon WH. The role of soft tissues in osteogenesis. An experimental study of canine spine fusions. *J Bone Joint Surg Am* 1959; 41-A: 1243-54.
- [56] von Arx T, Buser D. Horizontal ridge augmentation using autogenous block grafts and the guided bone regeneration technique with collagen membranes: a clinical study with 42 patients. *Clin Oral Implants Res* 2006; 17: 359-66.
- [57] Buser D, Brägger U, Lang NP, Nyman S. Regeneration and enlargement of jaw bone using guided bone regeneration. *Clin Oral Implants Res* 1990; 1: 22-32.
- [58] Dahlin C, Sennerby L, Lekholm U, Linde A, Nyman S. Generation of new bone around titanium implants using a membrane technique: an experimental study in rabbits. *Int J Oral Maxillofac Implants* 1989; 4: 19-25.
- [59] Barteck BK. The use of high density polytetrafluoroethylene membrane to treat osseous defects: clinical reports. *Implant Dent* 1995; 4: 21-6.
- [60] Jovanovic SA, Nevins M. Bone formation utilizing titanium reinforced barrier membranes. *Int J Periodontics Restorative Dent* 1995; 15: 56-69.
- [61] von Arx T, Kurt B. Implant placement and simultaneous periimplant bone grafting using microtitanium mesh for graft stabilization. *Int J Periodontics Restorative Dent* 1998; 18: 117-27.
- [62] Hämmerle CH, Jung RE. Bone augmentation by means of barrier membranes. *Periodontol* 2000 2003; 33: 36-53.
- [63] Jemt T, Lekholm U. Measurements of buccal tissue volumes at single implant restorations after local bone grafting in maxillas: a 3 year clinical prospective study case series. *Clin Implant Dent Relat Res* 2003; 5: 63-70.
- [64] Buser D, Brägger U, Lang NP, Nyman S. Regeneration and enlargement of jaw bone using guided tissue regeneration. *Clin Oral Implants Res* 1990; 1: 22-32.
- [65] Hockers T, Abensur D, Valentini P, Légrand R, Hammerle CH. The combined use of bioresorbable membranes and xenografts or autografts in the treatment of bone defects around implants. A study in beagle dogs. *Clin Oral Implants Res* 1999; 10: 487-98.
- [66] Rothamel D, Schwarz F, Sager M, Herten M, Sculean A, Becker J. Biodegradation of differently cross-linked collagen membranes: an experimental study in the rat. *Clin Oral Implants Res* 2005; 16: 369-78.
- [67] Bunyaratavej P, Wang HL. Collagen membranes: a review. *J Periodontol* 2001; 72: 215-29.
- [68] Wikesjö UM, Lim WH, Thomson RC, Cook AD, Wozney JM, Hardwick WR. Periodontal repair in dogs: evaluation of a bioabsorbable space providing macroporous membrane with recombinant human bone morphogenetic protein-2. *J Periodontol* 2003; 74: 635-47.

- [69] Stavropoulos F, Dahlin C, Ruskin JD, Johansson C. A comparative study of barrier membranes as graft protectors in the treatment of localized bone defects. An experimental study in a canine model. *Clin Oral Implants Res* 2004; 15: 435-42.
- [70] von Arx T, Broggin N, Jensen SS, Bornstein MM, Schenk RK, Buser D. Membrane durability and tissue response of different bioresorbable barrier membranes: a histologic study in the rabbit calvarium. *Int J Oral Maxillofac Implants* 2005; 20: 843-53.
- [71] Thoma DS, Halg GA, Dard MM, Seibl R, Hammerle CH, Jung RE. Evaluation of a new biodegradable membrane to prevent gingival ingrowth into mandibular bone defects in minipigs. *Clin Oral Implants Res* 2009; 20: 7-16.
- [72] Bone UMR. Formation by autoinduction. *Science* 1965; 150: 893-9.
- [73] Wozney JM, Rosen V, Celeste AJ, Mitscock LM, Whitters MJ, Kriz RW, et al. Novel regulators of bone formation: molecular clones and activities. *Science* 1988; 242: 1528-34.
- [74] Fiorellini JP, Howell TH, Cochran D, Malmquist J, Lilly LC, Spagnoli D, et al. Randomized study evaluating recombinant human bone morphogenetic protein-2 for extraction socket augmentation. *J Periodontol* 2005; 76: 605-13.
- [75] Howell TH, Fiorellini J, Jones A, Alder M, Nummikoski P, Lazaro M, et al. A feasibility study evaluating rhBMP-2/absorbable collagen sponge device for local alveolar ridge preservation or augmentation. *Int J Periodontics Restorative Dent* 1997; 17: 124-39.
- [76] Garg A. Bone morphogenetic protein (BMP) for sinus lift. *Dent Implantol Update* 2010; 21: 25-9.
- [77] Becker W, Lynch SE, Lekholm U, Becker BE, Caffesse R, Donath K, Sanchez R. A comparison of ePTFE membranes alone or in combination with platelet derived growth factors and insulin-like growth factor I or demineralized freeze dried bone in promoting bone formation around immediate extraction socket implants. *J Periodontol* 1992; 63: 929-40.
- [78] Canullo L, Trisi P, Simion M. Vertical ridge augmentation around implants using e-PTFE titanium reinforced membrane and deproteinized bovine bone mineral (Bio-Oss): a case report. *Int J Periodontics Restorative Dent* 2006; 26: 355-61.
- [79] Nevins M, Giannobile WV, McGuire MK, Kao RT, Mellonig JT, Hinrichs JE, et al. Platelet derived growth factor stimulates bone fill and rate of attachment level gain: results of a large multicenter randomized controlled trial. *J Periodontol* 2005; 76: 2205-15.
- [80] Marx RE, Carlson ER, Eichstaedt RM, Schimmele SR, Strauss JE, Georgeff KR. Platelet-rich plasma: growth factor enhancement for bone grafts. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 1998; 85: 638-46.
- [81] Smiler DG, Johnson PW, Lozada JL, Misch C, rosenlicht JL, Tatum OH Jr, Wagner JR. Sinus lift grafts and endosseous implants. Treatment of the atrophic posterior maxilla. *Dent Clin North Am* 1992; 36: 151-86.
- [82] Raghoobar GM, Brouwer TJ, Reintsema H, Van Oort RP. Augmentation of the maxillary sinus floor with autogenous bone for the placement of endosseous implants: a preliminary report. *J Oral Maxillofac Surg* 1993; 51: 1198-203.
- [83] Lundgren S, Moy P, Johansson C, Nilsson H. Augmentation of the maxillary sinus floor with particulated mandible: a histologic and histomorphometric study. *Int J Oral Maxillofac Implants* 1996; 11: 760-6.
- [84] Wood RM, Moore DL. Grafting of the maxillary sinus with intraorally harvested autogenous bone prior to implant placement. *Int J Oral Maxillofac Implants* 1988; 3: 209-14.
- [85] Shrime MG, Wilson TB, Eisig SB, Haddad J. Radiology quiz case 1: intraosseous schwannoma of the mandible. *Arch Otolaryngol Head Neck Surg* 2007; 133: 194-6.
- [86] Mellonig JT. Decalcified freeze-dried bone allograft as an implant material in human periodontal defects. *Int J Periodontics Restorative Dent* 1984; 4: 40-55.
- [87] de Lacerda SA, Brentegani LG, Rosa AL, Vespúcio MV, Salata LA. Intraosseous schwannoma of mandibular symphysis: case report. *Braz Dent J* 2006; 17: 255-8.
- [88] Misch CE, Dietsch F. Bone grafting materials in implant dentistry. *Implant Dent* 1993; 2: 158-67.
- [89] Boyne PJ, Re M, Nevins M, Triplett G, Lazaro E, Lilly LC, et al. A feasibility study evaluating rhBMP-2/absorbable collagen sponge for maxillary sinus floor augmentation. *Int J Periodontics Restorative Dent*. 1997; 17(1): 11-25.
- [90] Allegrini S Jr, Yoshimoto M, Salles MB, König B Jr. Bone regeneration in rabbit sinus lifting associated with bovine BMP. *J Biomed Mater Res B Appl Biomater* 2004; 68: 127-31.
- [91] Martins MD, Taghloubi SA, Bussadori SK, Fernandes KP, Palo RM, Martins MA. Intraosseous schwannoma mimicking a periapical lesion on the adjacent tooth: case report. *Int Endod J* 2007; 40: 72-8.
- [92] Wallace SS, Forum SJ, Cho SC, Elian N, Monteiro D, Kim BS, Tarnow DP. Sinus augmentation utilizing anorganic bovine bone (Bio-Oss) with absorbable and nonabsorbable membranes placed over lateral window: histomorphometric and clinical analysis. *Int J Periodontics Restorative Dent* 2005; 25: 551-9.
- [93] Jensen J, Sindet-Pedersen S, Oliver AJ. Varying treatment strategies for reconstruction of maxillary atrophy with implants: results in 98 patients. *J Oral Maxillofac Surg* 1994; 52: 210-6; Discussion: 16-8.
- [94] Doud Galli SK, Lebowitz RA, Giacchi RJ, Glickman R, Jacobs JB. Chronic sinusitis complicating sinus lift surgery. *Am J Rhinol* 2001; 15: 181-6.
- [95] Anavi Y, Allon DM, Avishai G, Calderon S. Complications of maxillary sinus augmentations in a selective series of patients. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2008; 106: 34-8.
- [96] Ilizarov GA. The tension stress effect on the genesis and growth of tissues. part I. The influence of stability of fixation and soft tissue preservation. *Clin Orthop Relat Res* 1989; 238: 249-81.
- [97] Rachmiel A, Jackson IT, Potparic Z, Laufer D. Midface vancement in sheep by gradual distraction: a one year follow up study. *J Oral Maxillofac Surg* 1995; 53: 525-9.
- [98] McCarthy JG, Schreiber J, Karp NS, Thorne CH, Grayson BH. Lengthening of the human mandible by gradual distraction. *Plast Reconstr Surg* 1992; 89: 1-8.
- [99] Rachmiel A, Levy M, Laufer D. Lengthening of the mandible by distraction osteogenesis: report of cases. *J Oral Maxillofac Surg* 1995; 53: 838-46.
- [100] Chin M, Toth BA. Distraction osteogenesis in maxillofacial surgery using internal devices: review of five cases. *J Oral Maxillofac Surg* 1996; 54: 45-53.
- [101] Stucki-McCormick SU. Reconstruction of the mandibular condyle using transport distraction osteogenesis *J Craniofac Surg* 1997; 8: 48-52.
- [102] Elsalanty ME, Taher TN, Zakhary IE, Al-Shahaat OA, Refai M, El-Mekkawi HA. Reconstruction of large mandibular bone and soft tissue defect using bone transport distraction osteogenesis. *J Craniofac Surg* 2007; 18: 1397-402.
- [103] Block MS, Chang A, Crawford C. Mandibular alveolar ridge augmentation in the dog using distraction osteogenesis *J Oral Maxillofac Surg* 1996; 54: 309-14.
- [104] Erkut S, Uckan S. Alveolar distraction osteogenesis and implant placement in a severely resorbed maxilla: a clinical report. *J Prosthet Dent* 2006; 95: 340-3.
- [105] Rachmiel A, Srouji S, Peled M. Alveolar ridge augmentation by distraction osteogenesis. *Int J Oral Maxillofac Surg* 2001; 30: 510-7.
- [106] Aparicio C, Jensen OT. Alveolar ridge widening by distraction osteogenesis: a case report. *Pract Proced Aesthet Dent* 2001; 13: 663-70.
- [107] Jensen OT, Cockrell R, Kuhike L, Reed C. Anterior maxillary alveolar distraction osteogenesis: a prospective 5 year clinical study. *Int J Oral Maxillofac Implants* 2002; 17: 52-68.
- [108] von Arx T, Kurt B. Implant placement and simultaneous periimplant bone grafting using microtitanium mesh for graft stabilization. *Int J Periodontics Restorative Dent* 1998; 18: 117-27.
- [109] Hidding J, Lazar F, Zöller JE. Initial outcome of vertical distraction osteogenesis of the atrophic alveolar ridge. *Mund Kiefer Gesichtschir* 1999; 3(Suppl 1): S79-83.
- [110] Simion M, Jovanovic SA, Trisi P, Scarano A, Piatteli A. Vertical ridge augmentation around dental implants using a membrane technique and autogenous bone or allografts in humans. *Int J Periodontics Restorative Dent* 1998; 18: 8-23.
- [111] Yalcin S, Ordu M, Emes Y, Gur H, Aktas I, Caniklioglu C. Alveolar distraction osteogenesis before placement of dental implants. *Implant Dent* 2006; 15: 48-52.
- [112] Zechner W, Bernhart T, Zauza K, Celar A, Watzek G. Multidimensional osteodistraction for correction of implant malposition in edentulous segments. *Clin Oral Implants Res* 2001; 12: 531-8.

- [113] Gaggl A, Schultes G, Rainer H, Kärcher H. The transgingival approach for placement of distraction implants. *J Oral Maxillofac Surg* 2002; 60: 793-6.
- [114] Laster Z, Rachmiel A, Jensen OT. Alveolar width distraction osteogenesis for early implant placement. *J Oral Maxillofac Surg* 2005; 63: 1724-30.
- [115] Wolvius EB, Scholtemeijer M, Weijland M, Hop WC, van der Wal KG. Complications and relapse in alveolar distraction osteogenesis in partially dentulous patients. *Int J Oral Maxillofac Surg* 2007; 36: 700-5.
- [116] Simion M, Baldoni M, Zaffe D. Jawbone enlargement using immediate implant placement associated with a split crest technique and guided tissue regeneration. *Int J Periodontics Restor- ative Dent* 1992; 12: 462-73.
- [117] Summers RB. A new concept in maxillary implant surgery: the osteotome technique. *Compendium* 1994; 15: 54-62.
- [118] Horowitz RA. The use of osteotome for sinus augmentation at the time at the time of implant placement. *Compend Contin Educ Dent* 1997; 18: 441-7, 540-4.
- [119] Ferrigno N, Laureti M. Surgical advantages with ITI TE implants placement in conjunction with split crest technique. 18 month results of an ongoing prospective study. *Clin Oral Implants Res* 2005; 16: 147-55.
- [120] Cruz M, Reis CC, Mattos FF. Implant induced expansion of atrophic ridges for the placement of implants. *J Prosthet Dent* 2001; 85: 377-81.
- [121] Shimoyama T, Kaneko T, Shimizu S, Kasai D, Tojo T, Horie N. Ridge widening and immediate implant placement: a case report. *Implant Dent* 2001; 10: 108-12
- [122] Guirado JL, Yuguero MR, Carrión del Valle MJ, Zamora GP. A maxillary ridge-splitting technique followed by immediate placement of implants: a case report. *Implant Dent* 2005; 14: 14-20.
- [123] Richardson D, Cawood JI. Anterior maxillary osteoplasty to broaden the narrow maxillary ridge *Int J Oral Maxillofac Surg* 1991; 20: 342-8.
- [124] Chiapasco M, Zaniboni M, Boisco M. Augmentation procedures for the rehabilitation of deficient edentulous ridges with oral implants. *Clin Oral Implants Res* 2006; 17(Suppl2): 136-59.
- [125] Coatoam GW, AM. The segmental ridge split procedure. *J Periodontol* 2003; 74: 757-70.
- [126] Foitzik C, Staus H. Le Fort I osteotomy in atrophied maxilla and bone regeneration with pure phase beta-tricalcium phosphate and PRP. *Implant Dent* 2003; 12: 132-9.
- [127] Turvey TA, White RP. Maxillary surgery. In: Proffit WR, White RP Jr, editors. *Surgical orthodontic treatment*. St. Louis: Mosby; 1991.p. 248-63.
- [128] Major PW, Philippon GE, Glover KE, Grace MG. Stability of maxilla downgrafting after rigid or wire fixation. *J Oral Maxillofac Surg* 1996; 54: 1287-91.
- [129] Jünger TH, Krenkel C, Howaldt HP. Le Fort I sliding osteotomy procedure for stable inferior repositioning of the maxilla. *J Craniomaxillofac Surg* 2003; 31: 92-6.
- [130] Reyneke JP, Masureik CJ. Treatment of maxillary deficiency by a Le Fort I downsliding technique. *J Oral Maxillofac Surg* 1985; 43: 914-6
- [131] Gaggl A, Rainer H, Chiari FM. Horizontal distraction of the anterior maxilla in combination with bilateral sinuslift operation preliminary report. *Int J Oral Maxillofac Surg* 2005; 34: 37-44.
- [132] Hwang SJ, Jung JG, Jung JU, Kyung SH. Vertical alveolar bone distraction at molar region using lag screw principle. *J Oral Maxillofac Surg* 2004; 62: 787-94.
- [133] Marx RE, Shellenberger T, Wimsatt J, Correa P. Severely resorbed mandible: predictable reconstruction with soft tissue matrix expansion (tent pole) grafts. *J Oral Maxillofac Surg* 2002; 60: 878-88; discussion 888-9.
- [134] Chiapasco M, Ferrini F, Casentini P, Accardi S, Zaniboni M. Dental implants placed in expanded narrow edentulous ridges with the extension crest device. A 1–3-year multicenter follow up study. *Clin Oral Implants Res* 2006; 17: 265-72.
- [135] Louis PJ, Gutta R, Said-Al-Naief N, Bartolucci AA. Reconstruction of the maxilla and mandible with particulate bone graft and titanium mesh for implant placement. *J Oral Maxillofac Surg* 2008; 66: 235-45.
- [136] Hoad-Reddick, G., Grant, A.A. & McCord, J.F. Osseoretention? Comparative assessment of particulate hydroxyapatite inserted beneath immediate dentures. *The European Journal of Prosthodontics and Restorative Dentistry* 1994; 3: 61-65.
- [137] Lekovic, V., Kenney, E.B., Weinlaender, M., Han, T., Klokkevold, P., Nedic, M. & Orsini, M.A bone regenerative approach to alveolar ridge maintenance following tooth extraction. Report of 10 cases. *Journal of Periodontology* 1997; 68: 563-570.
- [138] Bolouri, A., Haghghat, N. & Frederiksen, N. Evaluation of the effect of immediate grafting of mandibular postextraction sockets with synthetic bone *Compendium of Continuing Education in Dentistry* (Jamesburg, N.J.: 1995) 2001; 22: 955-958, 960, 962 passim; quiz 966.
- [139] Oghli, A.A. & Steveling, H. Ridge preservation following tooth extraction: a comparison between atraumatic extraction and socket seal surgery. *Quintessence International* 2010; 41: 605-609.
- [140] Araujo, M., Linder, E., Wennstrom, J. & Lindhe, J. The influence of Bio-Oss Collagen on healing of an extraction socket: an experimental study in the dog. *The International journal of periodontics & restorative dentistry* 2008; 28: 123-135.
- [141] Araujo, M.G. & Lindhe, J. Socket grafting with the use of autologous bone: an experimental study in the dog. *Clinical oral implants research* 2011; 22: 9-13.
- [142] Ten Heggeler, J.M., Slot, D.E. & Van der Weijden, G.A. Effect of socket preservation therapies following tooth extraction in non-molar regions in humans: a systematic review. *Clinical Oral Implants Research* 2010; 22: 779-788.
- [143] Vignoletti F, Matesanz P, Rodrigo D, Figuero E, Martin C, Sanz M. Surgical protocols for ridge preservation after tooth extraction. A systematic review. *Clin. Oral Impl. Res* 2012; 23(Suppl. 5), 22-38.
- [144] Fickl, S., Zuhr, O., Wachtel, H., Bolz, W. & Huerzeler, M. Tissue alterations after tooth extraction with and without surgical trauma: a volumetric study in the beagle dog. *Journal of Clinical Periodontology* 2008a; 35: 356-363.
- [145] Fickl, S., Zuhr, O., Wachtel, H., Stappert, C.F., Stein, J.M. & Huerzeler, M.B. Dimensional changes of the alveolar ridge contour after different socket preservation techniques. *Journal of Clinical Periodontology* 2008b; 35: 906-913.
- [146] Amler, M.H., Johnson, P.L. & Salman, I. Histological and histochemical investigation of human alveolar socket healing in undisturbed extraction wounds. *Journal of the American Dental Association* 1960; 61: 32-44.
- [147] Froum, S., Cho, S.C., Rosenberg, E., Rohrer, M. & Tarnow, D. Histological comparison of healing extraction sockets implanted with bioactive glass or demineralized freeze-dried bone allograft: a pilot study. *Journal of Periodontology* 2002; 73: 94-102.
- [148] Aimetti M, Romano F, Griga FB, Godio L. Clinical and histologic healing of human extraction sockets filled with calcium sulfate. *Int J Oral Maxillofac Implants* 2009; 24(5): 902-909.
- [149] Guarneri R, Pecora G, Fini M, Aldini NN, Giardino R, Orsini G et al. Medical grade calcium sulfate hemihydrate in healing of human extraction sockets: clinical and histological observations at 3 months. *J Periodontol* 2004; 75: 902-908.
- [150] Nevins M, Camelo M, De Paoli S, Friedland B, Schenk RK, Parma-Benfenati S et al. A study of the fate of the buccal wall of extraction sockets of teeth with prominent roots. *Int J Periodontics Restor Dent* 2006; 26: 19-29.
- [151] Serino G, Rao W, Iezzi G, Piattelli A. Polylactide and polyglycolide sponge used in human extraction sockets: bone formation following 3 months after its application. *Clin Oral Implants Res* 2008; 19: 26-31.
- [152] Albertsson T, Dahl E, Enbom L, Engvall S, Enquist B, Eriksson AR, et al. Osseointegrated oral implants. A Swedish multicenter study of 8139 consecutively inserted Nobel Pharma implants. *J Periodontol* 1988; 59: 287-96.
- [153] Reddy MS, Geurs NC, Wang IC, Liu PR, Hsu YT, Jeffcoat RL, Jeffcoat MK. Mandibular growth following implant restoration: does Wolff's law apply to residual ridge resorption? *Int J Periodontics Restorative Dent* 2002; 22: 315-21.
- [154] Keller EE, Desjardins RP, Tolman DE, Laney WR, Van Roekel NB. Reconstruction of the severely resorbed mandibular ridge using the tissue integrated prosthesis. *Int J Oral Maxillofac Implants* 1986; 1: 101-9.
- [155] Cardaropoli G, Arajo M, Lindhe J. Dynamics of bone tissue formation in tooth extraction sites. An experimental study in dogs. *J Clin Periodontol* 2003; 30: 809-8187.
- [156] Lang NP, Schild U, Brügger U. Effect of chlorhexidine (0.12 %) rinses on periodontal tissue healing after tooth extraction. (I).

- Clinical parameters. *J Clin Periodontol* 1994; 21: 415-421
- [157] Saldanha JB, Casati MZ, Neto FH, Sallum EA, Nociti FH Jr. Smoking may affect the alveolar process dimensions and radiographic bone density in maxillary extraction sites: a prospective study in humans. *J Oral Maxillofac Surg.* 2006; 64: 1359-1365.
- [158] Anitua E Plasma rich in growth factors: preliminary results of use in the preparation of future sites for implants. *Int J Oral Maxillofac Implants* 1999; 14: 529-535.
- [159] Camargo PM, Lekovic V, Weinlaender M, Klokkevold PR, Kenney EB, Dimitrijevic B et al Influence of bioactive glass on changes in alveolar process dimensions after exodontia. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2000; 90: 581-586.