Surgical Algorithm for Alveolar Bone Augmentation in Implant Dentistry

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KEYWORDS

• Dental implantation • Bone augmentation • Surgical algorithm • Cone-beam computed tomography • Ridge-split • Block graft • Distraction osteogenesis • Guided bone regeneration

KEY POINTS

- Surgical algorithm can help to determine the best bone augmentation technique for a particular patient in a systematic manner.
- Bone augmentation procedures can be classified on the base of their degree of vascularization that defines their biologic rationale.
- Replacement of failing or ailing natural teeth with dental implants has become an alternative treatment option since the discovery of osseointegration by Dr. P-I Brånemark in the early 1960s.
- A team approach is the best way to evaluate and devise a treatment plan for an implant patient.
- Use of modern 3D CBCT imaging technology helps to diagnose and treat bone deficiency and idealize implant positioning.

INTRODUCTION

Replacement of failing or ailing natural teeth with dental implants has become an alternative treatment option since the discovery of osseointegration by P.-I. Brånemark in the early 1960s.[1–4] Since the early 1980s, surgical-restorative treatment with dental implants become mainstream dentistry.[5,6] Originally surgically driven, the definition of success was an actual osseointegration of titanium implant screw without regard to prosthetics and occlusion. Later, the restoratively driven concept became prevalent with placement of implants linked to proper function and occlusion.[7–10] With time, both surgical and restorative colleagues had to find a common understanding to place implants in the alveolar ridge that would provide functional implant restorations. Techniques and a variety of methods of alveolar bone reconstruction have slowly developed to accommodate the restorative necessity of proper implant placement. A team approach is the best way to evaluate and devise a treatment plan for an implant patient. Use of modern 3D cone-beam computed tomography (CBCT) imaging technology helps to diagnose and treat bone deficiency and idealize implant positioning.

Alveolar bone grafting can be divided into ridge preservation and ridge augmentation.

Ridge preservation (prophylactic approach) involves hard and soft-tissue grafting procedures that intend to preserve the existing ridge volume within its bony envelope; they are usually performed at the time of tooth extraction with the

Disclosure: The author has nothing to disclose.

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Oral Maxillofacial Surg Clin N Am ■ (2019) ■–■
https://doi.org/10.1016/j.coms.2019.01.001

goal of minimizing tissue loss after the tooth loss. This surgical approach tends to mostly involve an interpositional or inlay bone grafting with a bone material (routinely, a particulate graft) placed in between the walls of a fresh (postextraction) tooth socket. Ridge preservation using guided bone regeneration (GBR) and guided tissue regeneration (GTR) techniques helps to decrease or eliminate larger surgical bone augmentation procedures.[11,12] An accepted objective after successful grafting is to place a restoratively driven dental implant(s) 3 to 6 months later into mature bony housing. Immediate implantation is possible if primary implant stability can be achieved.[13,14] Although complete prevention of bone collapse with ridge preservation techniques is challenging, the objective here is to minimize it as much as possible.[15–17]

Ridge augmentation (treatment approach) involves hard and soft-tissue grafting procedures that intend to increase (augment) the alveolar ridge volume beyond the existing skeletal envelope; they are usually performed at the edentulous state of a collapsed or deficient alveolar ridge. This surgical approach can involve an onlay (external) or inlay (internal) technique of bone grafting, as well as distraction methods. An accepted objective after successful grafting is to place a restoratively driven dental implant(s) 4 to 6 months later into a mature bony housing. Immediate implantation, in some cases, is possible, if primary implant stability can be achieved.[18] Overcorrection in bone augmentation is often deliberate, knowing the tendency of bone to remodel with some degree of relapse and resorption over time.[19,20]

This article focuses on bone augmentation techniques, which can mainly be classified into horizontal bone augmentation (HBA) and vertical (volumetric) bone augmentation (VBA).

SURGICAL ALGORITHM FOR ALVEOLAR BONE AUGMENTATION

A rationale for a particular bone augmentation procedure in oral implantology originates from the very beginning—the patient's consultation—using clinical and radiographic data. The patient's complaints (symptoms) as well as objective signs of the oral condition lead to a diagnosis and treatment plan. The surgeon's knowledge, skills, and preferences will ultimately dictate the particular bone augmentation technique used.

Ten specific treatment questions (Qs) outlined below can help a surgeon to follow a targeted surgical algorithm to determine the best bone augmentation technique for a particular patient in a logical manner (Fig. 1).

Surgical algorithm based on 10 systematic diagnostic questions

Q1: Does the patient lack function of mastication or have esthetic compromise caused by a missing tooth or teeth in the particular area of the jaw?

Example: when a missing tooth would not compromise the function of mastication such as a missing second maxillary molar or mandibular incisor, there may be no discernible lack of function or esthetics.

- If the answer is "Yes", the next question is:

Q2: What would be the most efficient and long-lasting method to improve function, esthetics, and comfort for this patient:

- With restorative means only or through a
- Surgical-restorative approach?

  Example: a fixed bridge would become a favorable treatment if both abutment teeth have crowns and advanced bone loss is present in the pontic region, dictating an extensive vertical ridge augmentation.

  - If the answer is surgical-restorative approach (implant), the next question is:

Q3: Does the patient have sufficient bone stock (foundation) to accommodate an endosseous implant (implants) for the restorative goal selected (eg, single implant crown, 2- to 3-unit implant bridge, full-arch implant rehabilitation)? Use of CBCT scan is encouraged at this stage but not mandatory.

- If the answer is "No", that is, there is bone deficiency present, the next question is

Q4: Does the patient have mainly a horizontal bone defect (HBD), a vertical bone defect (VBD), or a composite bone defect (HDB/VDB)? Clinical and 3D radiographic evaluation with CBCT images can help to answer this question and determine the need for an HBA, a VBA, or both.

- Now, it is important to determine the degree of bone deficiency (horizontal or vertical).

Q5H and *Q5V*: Determine the severity (mild, moderate, severe) of the alveolar ridge deficiency. This can be determined based on the need to accommodate typical root-form dental implant of 4 mm diameter (D) and 10 mm length (L) (4×10). Both 2D and 3D imaging is important.

Alveolar Bone Classification by Deficiency (ABCD) (Tolstunov classification):

HBD (WIDTH compromise): types

0. No HBD is present

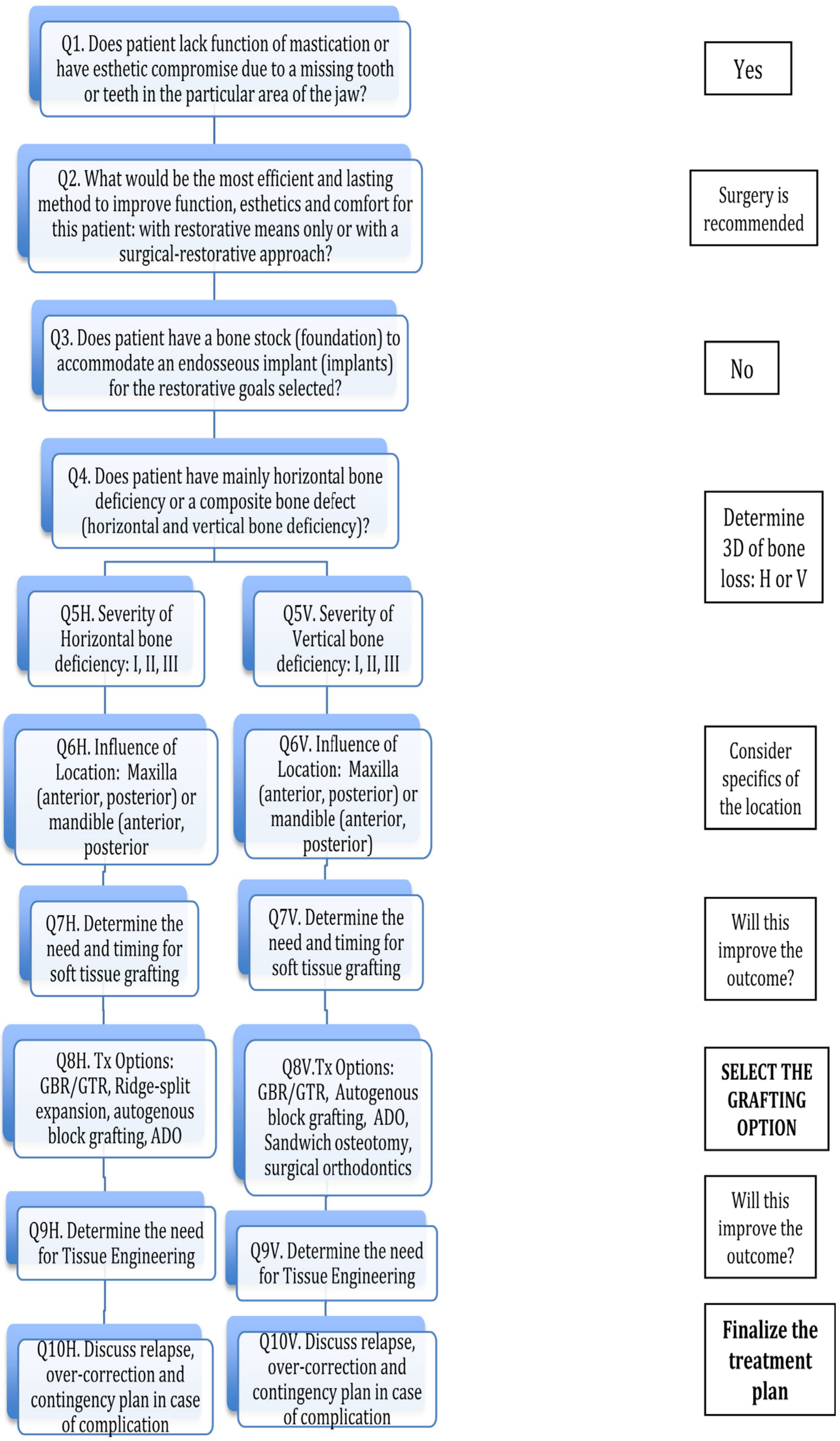

Fig. 1. 10-point surgical algorithm of implant-driven alveolar bone reconstruction in oral implantology.

I. Mild HBD = 7 to 9 mm of alveolar width is present
II. Moderate HBD = 4 to 7 mm is remaining
III. Severe HBD = less than 4 mm is present

VBD (HEIGHT compromise): types

0. No VBD is present
I. Mild VBD = 7 to 9 mm of alveolar height is present
II. Moderate VBD = 4 to 7 mm is remaining
III. Severe VBD = less than 4 mm is present

Variants of alveolar bone loss:

1. Patient has mainly *horizontal* bone deficiency (I, II, or III),
2. Patient has mainly *vertical* bone deficiency (I, II, or III),
3. Patient has a *combination* bone defect: I/I or II/I, or III/III, etc., where the first number indicates horizontal deficiency and the second, vertical.

Example: If a patient's posterior maxillary ridge has 6 mm of edentulous ridge width and 8 mm of alveolar height from the alveolar crest to the sinus floor, this will be type II/I bone defect according to Tolstunov ABCD classification. It means that a surgeon should concentrate mainly on correction of the HBD (from 6 mm to 10 mm) and also improve bone height in a staged or simultaneous fashion trying to achieve 10 x 10 stock of bone.

After determining the bone defect (its dimension and extent), one can proceed to the next algorithmic questions (Q6 and Q7) before making a decision on a particular bone-grafting technique (Q8, Q9, and Q10).

Q6H and *Q6V*: Think about the location, that is, how a particular location of the alveolar ridge would influence or modify the selected diagnosis and treatment plan. Pay attention to the following:

1. Anterior maxilla (incisor, canine, and first premolar):
   a. Evaluate labial cortical plate deficiency (horizontal collapse is very common) and the extent of HBD versus VBD
   b. Determine exacerbating history of:
      i. Apicoectomy(ies) where one would expect periapical bone loss
      ii. Traumatic accident(s) where one would expect horizontal bone loss with scarring and associated vascular compromise
      iii. Pathologic lesion(s) where one would expect a large defect after excision
   c. Consider bone-grafting methods including particulate GBR, block, or alveolar distraction osteogenesis (ADO).
   d. Next, evaluate the soft-tissue envelope and esthetic profile including the presence of keratinized gingiva, gingival biotype, esthetic score, smile line, transition line, and other esthetic parameters. Consider soft tissue grafting prior to bone grafting when type III/III bone defect (Tolstunov ABCD classification) is present or after bone grafting when type II/II or smaller bone defect is present.
   e. Key surgical considerations for implant treatment in anterior maxilla:
      i. Using a staged approach with delayed implant placement
      ii. Tapered internal hex implants with diameter of 3.5 to 4.2 mm, placed 3 mm subcrestally
      iii. 3+ mm of buccal bone in front of the implant will improve longevity and success
   f. Prosthetics:
      i. Placement of a temporary fixed or removable prosthesis after the surgery (eg, Maryland bridge or Essex appliance) with no occlusal pressure
      ii. Placement of a *definitive* prosthesis 8 to12 months after the initial bone augmentation procedure into a fully matured bone
2. Posterior maxilla (second premolar, first molar, and second molar):
   a. Type 3 and 4 bone (poor bone density) that lowers overall implant success
   b. Maxillary sinus pneumatization often requires VBA through the crestal or indirect sinus lift for type I and II VBD (ABCD classification) with more than 4 mm of bone present or lateral or direct sinus lift for type III VBD with less than 4 mm of bone present
   c. For the posterior zone of mastication, one should consider 1 implant per missing tooth and splinting of implant restorations,
   d. Avoid single implants in the second molar position (highest failure rate)
3. Anterior mandible (incisor, canine, and first premolar):
   a. Often horizontal bone deficiency is present
   b. Consider 2 implants to support 3 to 6 missing teeth
   c. Consider evaluating the location of the sublingual artery extension into the symphyseal part of the mandible to prevent vascular injury and a potential for severe bleeding
4. Posterior mandible (second premolar, first molar, and second molar):
   a. Consider an inferior alveolar nerve proximity of 3 mm to be an adequate safety zone

b. Combination bone defect (HBD + VBD) with a staged surgical approach
c. For this zone of mastication, 2 to 3 implants are ideal for 3 to 4 missing teeth
d. Avoid single implants in the second molar position

5. Full Arch:
   a. Fixed or removable full-arch implant rehabilitation choices are based on quality of remaining dentition (if present), remaining bone stock, patient's systemic condition and desires, and surgical-restorative team experience
   b. All-On-4, zygomatic, and pterygoid implant approaches with either delayed or immediate prosthetics are alternative treatment options that require an advanced surgical and restorative training for success

Q7H and *Q7V*: Determine the need for soft-tissue grafting (quantity and quality of soft-tissue envelope) that can be done before or after the bone grafting and implant treatment using, for example, free palatal graft or connective tissue graft

- If the answer is "No," bone deficiency treatment is the priority. The next question is:

Q8H and *Q8V*: What would be the most predictable and least invasive method of HBA or VBA that would enable placement of implant(s) with a lasting function, esthetics, and comfort?

- Suggested surgical treatment options for HBD based on Tolstunov ABCD classification:
  1. GBR/GTR with a particulate graft for types I and II HBD
  2. Ridge-split expansion procedure (RSEP) with a particulate graft for types I and II HBD
  3. Autogenous block bone (ABB) graft for types II and III HBD
- Suggested surgical treatment options for VBD based on Tolstunov ABCD classification:
  1. Surgical orthodontics (forced eruption) for type I VBD
  2. GBR/GTR with a particulate graft and Ti-reinforced membrane or Ti-mesh (protected GBR) for types I, II and III VBD
  3. ABB graft for types II and III VBD
  4. Segmental sandwich osteotomy (SSO) with a particulate or block graft for types II and III VBD
  5. Alveolar distraction osteogenesis (ADO) procedure for types II and III VBD

Q9H and *Q9V*: At this point, the need for biomimetics for advanced tissue engineering such as for use in the treatment of complex reconstructive cases, large bone defects, or compromised immune response/compromised healing history, or both, consider the use of bone morphogenetic protein-2, platelet-rich plasma, platelet-rich fibrin, and bone marrow aspirate to enhance bone regeneration and/or bone growth.

Q10H and *Q10V*: Consider a contingency plan in cases of complication and loss of a graft. Consider the possibility of relapse of each bone-grafting procedure. Consider overcorrection.

When both a surgeon and restorative implant practitioner follow this surgical algorithm, he or she would have very few unanswered questions before selecting the best bone augmentation technique for each particular case of alveolar bone defect as related to implant dentistry (see **Fig. 1**).

BIOLOGIC RATIONALE OF A SURGICAL PROCEDURE: BONE AUGMENTATION

Although many key surgical principles, such as stabilization of bone fragments, fixation of the jaws, space maintenance, and proper wound closure, are important for success, vitality of bone segments seems to be the key surgical principle. Continuous adequate vascularization to bone fragments and grafts is exceedingly important and relies on central (centrifugal or endosteal) and peripheral (centripetal or periosteal) blood supply. Many surgical procedures can be classified by this principle as having higher or lower biologic rationale (BR).[21]

Vascularized bone free flap is a bone augmentation procedure with instant revascularization of tissues by means of a microvascular anastomosis. Among many distant bone free flaps, reconstruction of large mandibular defects with free fibular osteocutaneous flap is often selected for patients with cancer. Establishment of a central anastomosis with a recipient artery leads to full reperfusion of transferred bone and soft tissues (**Table 1**).

ADO is performed for mostly vertically deficient alveolar ridges. The vitality of the osteotomized (transport) bone segment is preserved from 2 vascular sources: endosteal (through the slow separation of fragments at a distraction rate of about 1-mm per day) and peripheral (through the intact and slow-stretching mucoperiosteal flaps). This technique provides an uninterrupted vascular supply important for bone healing that starts with woven (embryonic) bone formation and progresses to lamellar (mature) bone. The BR of the ADO is very high and may only be considered slightly behind the microvascular flap (see **Table 1**).

The RSEP is used for horizontal ridge augmentation. It is an excellent example of pedicled

Table 1
Stratification of bone augmentation procedures by their biologic rationale (BR) (vascularization)

Surgical Techniques	Biologic Rationale (1 to 5 Stars)	Vascularization (Type)	Revascularization (Reperfusion)
Free bone-soft tissue flap transfer	*****	Central (reperfusion)	Optimal to all transferred donor tissues
Distraction osteogenesis	****	Periosteal and endosteal preserved for mobilized bone segments	Optimal, dual (endosteal and periosteal), uninterrupted
Ridge-split expansion, pedicled sandwich osteotomy, ridge preservation, tunnel technique, sinus lift	***	Periosteal for mobilized bone segment and endosteal for inlay bone graft	Optimal periosteal but some loss of endosteal vascularity to the fractured bone segment
Autogenous onlay block bone graft, Ti-mesh or Tent-pole with nonresorbable membrane	**	Plasmatic imbibition (endosteal)	Slow endosteal reperfusion, delayed or missing periosteal source
Cortical tenting (cortical bone block tented over a defect filled with particulate material)	*	Plasmatic imbibition to particulate graft (endosteal), none (initially) to tented cortical block bone	Detached block bone undergoes delayed, partial, and poor revascularization

*****, outstanding vascularization is realized during and after the surgical procedure, BR = 5; ****, excellent vascularization is achieved during and after the surgical procedure, BR = 4; ***, good vascularization is attained during and after the surgical procedure, BR = 3; **, marginal vascularization is realized during and after the surgical procedure, BR = 2; *, poor vascularization is achieved during and after the surgical procedure, BR = 1.

From Tolstunov L. Biologic rationale of a surgical procedure: bone augmentation. J Oral Maxillofac Surg 2018;76(5):915; with permission.

segmental osteotomy[22,23] with optimal vascularization preserved throughout the entire procedure. Continuous blood supply is provided through the peripheral source of intact periosteum attached to the mobilized bone segment, as well as central endosteal source from the trabecular bone feeding the interpositional (inlay) particulate bone graft placed between bone segments. Loss of endosteal vascularity to the subfractured bone segment is the only temporary drawback and is usually well compensated by the peripheral source in the osteoperiosteal flap. Pedicled sandwich osteotomy is a modification of the alveolar split that is used for vertical ridge augmentation, and has the same robust vascularization basis. Postextraction ridge preservation through GBR, tunnel technique, and sinus lift are other methods of internal bone grafting with a particulate graft placed into a 2-to-4 wall defect (socket, collapsed alveolar ridge, or subantral pocket) that is protected and well vascularized with both endosteal and periosteal sources (see **Table 1**).

ABB grafting (extraoral or intraoral) is performed for mainly horizontally deficient alveolar ridges. This is an onlay bone block graft that is separated from its original source of vascularization (donor site) and transferred to the collapsed alveolar ridge. Vitality of transferred graft is temporarily interrupted. It is also not consistently restored. The early route of nurture for the free donor block bone is from the recipient site by plasmatic imbibition from the endosteum via the formation of "vascular sprouts,"[24] which is a slow reperfusion process from the underlying bone that provides marginal vascularization of the grafted bone during the early bone healing. The graft initially undergoes bone resorption followed by a cycle of bone modeling and remodeling leading to a delayed bone formation. With regard to the periosteal source of vitality for a block graft, detached periosteum eventually revascularizes the bone block from the periphery 2 to 4 weeks later, a delayed contribution to overall bone healing.

Ti-mesh and Tent-pole bone augmentation methods used with non-resorbable dense polytetrafluoroethylene (d-PTFE) membrane techniques are other methods of protected onlay bone augmentation having a single endosteal source of blood supply. Frequent exposure and infection of these devices are common as the body attempts to rid itself of the "foreign body" and re-establish missing periosteal vascularization to feed the particulate graft underneath. Because of the missing or delayed periosteal or endosteal source of blood supply, the BR of ABB and Ti-reinforced graft success can be modest (see **Table 1**).

It seems that success of segmental bone osteotomies and bone-grafting procedures depends profoundly on initial revascularization from 2 primary sources of blood supply, endosteal (central) and periosteal (peripheral). Early vitality of osteotomized bone segments is critically important for early bone healing initiated as bone modeling, which forms a callus of woven bone matrix followed later by bone remodeling and maturation. Late-term bone loss or resorption is associated with interruption of vascularization during different stages of bone and implant reconstruction.

The BR of any surgical procedure is defined by the quality of vascularization and preservation of blood supply throughout the surgery. This determines the success of bone and soft-tissue healing and the ultimate success of a surgical technique. Surgical practitioners should always attempt to select a procedure with the utmost potential for physiologic healing, with the highest BR.

REFERENCES

1. Branemark PI, Adell R, Breine U, et al. Intra-osseous anchorage of dental prostheses. I. Experimental studies. Scand J Plast Reconstr Surg 1969;3:81–100.
2. Adell R, Hansson BO, Branemark PI, et al. Intra-osseous anchorage of dental prostheses. II. Review of clinical approaches. Scand J Plast Reconstr Surg 1970;4:119–34.
3. Branemark PI, Breine U, Hallen O, et al. Repair of defects in mandible. Scand J Plast Reconstr Surg 1970;4:2100–8.
4. Adell R, Lekholm U, Rockler B, et al. A 15-year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Surg 1981;10:6387–416.
5. Attard NJ, Zarb GA. Long-term treatment outcomes in edentulous patients with implant overdentures: the Toronto study. Int J Prosthodont 2004;17:4425–33.
6. Attard NJ, Zarb GA. Long-term treatment outcomes in edentulous patients with implant-fixed prostheses: the Toronto study. Int J Prosthodont 2004;17:4417–24.
7. Sones AD. Complications with osseointegrated implants. J Prosthet Dent 1989;62:5581–5.
8. Tinsley D, Watson CJ, Preston AJ. Implant complications and failures: the fixed prosthesis. Dent Update 2002;29:9456–60.
9. Watson CJ, Tinsley D, Sharma S. Implant complications and failures: the complete overdenture. Dent Update 2001;28:5234–8, 240.
10. Watson CJ, Tinsley D, Sharma S. Implant complications and failures: the single-tooth restoration. Dent Update 2000;27:135–8, 40, 42.
11. Mellonig JT, Triplett RG. Guided tissue regeneration and endosseous dental implants. Int J Periodontics Restorative Dent 1993;13:2108–19.
12. Tomlin EM, Nelson SJ, Rossmann JA. Ridge preservation for implant therapy: a review of the literature. Open Dent J 2014;8:66–76.
13. Masaki C, Nakamoto T, Mukaibo T, et al. Strategies for alveolar ridge reconstruction and preservation for implant therapy. J Prosthodont Res 2015;59:4220–8.
14. Zeren KJ. Minimally invasive extraction and immediate implant placement: the preservation of esthetics. Int J Periodontics Restorative Dent 2006;26:2171–81.
15. Buser D, Chappuis V, Belser UC, et al. Implant placement post extraction in esthetic single tooth sites: when immediate, when early, when late? Periodontol 2000 2017;73:84–102.
16. Buser D, Halbritter S, Hart C, et al. Early implant placement with simultaneous guided bone regeneration following single-tooth extraction in the esthetic zone: 12-month results of a prospective study with 20 consecutive patients. J Periodontol 2009;80:1152–62.
17. Raes S, Eghbali A, Chappuis V, et al. A long-term prospective cohort study on immediately restored single tooth implants inserted in extraction sockets and healed ridges: CBCT analyses, soft tissue alterations, aesthetic ratings, and patient-reported outcomes. Clin Implant Dent Relat Res 2018;20(4):522–30.
18. Cortese A, Pantaleo G, Amato M, et al. Ridge expansion by flapless split crest and immediate implant placement: evolution of the technique. J Craniofac Surg 2016;27:2e123–8.
19. Chappuis V, Cavusoglu Y, Buser D, et al. Lateral ridge augmentation using autogenous block grafts and guided bone regeneration: a 10-year prospective case series study. Clin Implant Dent Relat Res 2017;19:185–96.
20. Chiapasco M, Abati S, Romeo E, et al. Clinical outcome of autogenous bone blocks or guided bone regeneration with e-PTFE membranes for the reconstruction of narrow edentulous ridges. Clin Oral Implants Res 1999;10:4278–88.
21. Ewers R, Tomasetti B, Ghali G, et al. A new biologic classification of bone augmentation. In: Jensen OT, editor. The osteoperiosteal flap: a simplified approach to alveolar bone reconstruction. Chicago: Quintessence Publishing; 2010. p. 19–42.
22. Bell WH. Revascularization and bone healing after anterior maxillary osteotomy: a study using adult rhesus monkeys. J Oral Surg 1969;27:4249–55.
23. Bell WH, Levy BM. Revascularization and bone healing after anterior mandibular osteotomy. J Oral Surg 1970;28:3196–203.
24. De Marco AC, Jardini MA, Lima LP. Revascularization of autogenous block grafts with or without an e-PTFE membrane. Int J Oral Maxillofac Implants 2005;20:6867–74.