Microsurgery in Guided Bone Regeneration

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Contents

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Abstract

Guided bone regeneration (GBR) is the process of replacing lost tissues with elements to restore normal function and structure for ideal three-dimensional placement of dental implants. GBR is based on guided tissue regeneration and has common mechanical and biological principles; their similarities are obvious throughout the evolution of bone regeneration concepts. There are four fundamental biological principles for successful GBR: primary wound closure, adequate blood supply, clot stability, and space maintenance.

Microsurgery was introduced in Periodontology in 1992 for the improvement of surgical techniques. It was made possible by the advancements in visual acuity obtained through the microscope. Microsurgery helps develop motor skills by improving surgical capacity, reduces tissue trauma, and contributes to the primary closure of the wound.

The proposed use of the microscope in GBR can aid precision in surgical execution. It has been shown that microsurgery contributes to improved healing and treatment outcomes in other areas of Periodontology.

This chapter provides a detailed description of GBR techniques using a surgical microscope (MO) along with information on the elements essential for the application of this technology. The principles of magnification and coaxial light and fundamentals of microsurgery are used for the execution of incisions, release of flaps, preparation of the surgical bed, handling of biomaterials, and membrane fixation, complementing the techniques for flap closure and soft tissue management in regenerative therapy.

Keywords

Bone regeneration · Microsurgery · Microscopic periodontal surgery Microsurgery in bone regeneration therapy · Microsurgery in process augmentation · Microsurgical flap · Microsurgical regenerative therapies

1 Introduction

Regenerative therapy replaces tissues lost by injury or disease with new elements of high organizational disposition to restore normal function and structure. Augmentation procedures for the maxillaries have evolved to offer predictable results. Under optimal conditions, the reconstruction of the original structure and function of the bone tissue can occur.

Predictable success of guided bone regeneration (GBR) depends mainly on four important biologic principles: primary wound closure, adequate blood supply, clot stability, and space maintenance. [1] This chapter discusses the microsurgical approach in regenerative therapy, with an emphasis on the precision and additional clinical benefits it offers.

1.1 History of Guided Bone Regeneration

GBR is based on guided tissue regeneration, and they have common mechanical and biological principles; [2] their similarities can be observed throughout the evolution of the concepts of osseous regeneration [3, 4].

Several authors have reported difficulties in the placement of prostheses at edentulous sites due to post-extraction alveolar ridge resorption. This resorption is more accentuated on the buccal bone plate of both maxillaries. The buccal bone is thinner in most cases and undergoes post-extraction resorption, complicating prosthetic rehabilitation [5–7]. On many occasions, the use of dental materials was shown to resolve the esthetic concerns associated with these deficiencies. Further, implementing surgical soft tissue techniques can improve both esthetic and functional outcomes; [8] however, the lost structures cannot be completely restored. With the development of implantology, bone regeneration has become a priority.

Several studies have described morphological changes in the post-extraction healing of alveolar tissue [6, 7, 9]. Araujo and Lindhe demonstrated the occurrence of significant three-dimensional alteration of the alveolar ridge within 4–8 months after extraction, with a reduced buccal and lingual ridge height; the vestibular region was most affected [10]. The researchers also described horizontal bone loss accompanying the destruction of the alveolar height. Prospective clinical studies and systematic reviews have demonstrated significant variation in the post-extraction changes within the first 12 months, although the first 3 months are the most critical [11, 12]. The situation is further compromised when the alveolus loses height because of trauma, periodontal disease, periapical pathologies, or damage caused during the extraction [11, 13].

An understanding of osseous deficiencies, tissue management, and regenerative materials is necessary to determine the clinical prognosis of GBR [14]. The developed techniques comply with biological and functional demands and have improved the treatment outcomes to satisfactory levels [15]. Microsurgery can further improve the outcomes of these techniques and allow better predictability.

1.2 Development of Microscopic Surgery and its Application in Regenerative Bone Therapy

Microsurgery improves the execution of each surgical step in GBR and allows more predictable results than conventional bone regeneration surgery. These improvements result from the precision, accuracy, and gentle treatment of tissues made possible under magnification, in addition to improved techniques for autogenous tissue procurement, membrane fixation, and wound closure.

1.2.1 History

Microsurgery was introduced in periodontics in 1992, [16] and its application has since evolved with introduction in different aspects of periodontal treatment [17–24]. In 1962, osseous reconstructive microscopic surgery was introduced in traumatology for vascularized bone flap transfers for the reconstruction of traumatic tibial defects [25]. Therefore, GBR has been performed under the microscope for benefits already demonstrated in other areas of medicine, such as traumatology, since the 1970s, and in several areas of periodontics, since the 1990s [26].

Microscope is a modern surgical accessory and a critical factor for the success of the most complex medical surgeries performed today. The emergence of this tool reflects the advances in the principles of optics [27].

Currently, there is no scientific evidence to support the benefits of microsurgery in GBR. Research results are based primarily on patients' subjective opinions and the observations of the microsurgeon performing the procedure. Microscopic surgery is still in its early stages of development in periodontics and implantology and is considered an area of great potential for prospective analyses comparing macro and microsurgical techniques to demonstrate the benefits of the latter.

1.3 Importance of the Surgical Microscope in GBR

The microsurgical approach enhances the efficiency of the operator with consistent treatment outcomes [28].

The application of microsurgical principles starts by evaluating the surgical site indicated for augmentation. Further, preparation of tissues with nonsurgical therapy under magnification can give better results than treatment without magnification.

Fig. 1 (**a**, **b**) Microscope-assisted guided bone regeneration

Microscope-assisted GBR can enhance the surgeon's performance by enabling precise placement of surgical incisions and elevation of the flap using microsurgical instruments designed to induce minimal tissue trauma. Magnification and illumination allow suitable handling of materials, and microsurgical suturing techniques produce less tissue damage and promote primary wound closure [17, 28, 29] Video 1 and Fig. 1a, b.

2 Biological Basis and Anatomical Consideration During Microscope-Assisted GBR

The restoration of lost or absent tissue requires comprehension of the biological structures to be regenerated. A predictable procedure should consider the biological mechanisms of bone regeneration. A range of techniques have been proposed to induce bone formation and restore alveolar defects, for example, osteoinduction by bone grafts or growth factors, osteoconduction by bone grafts substitutes that serve as scaffolds for new bone formation, osteodistraction, forced extrusion orthodontics, and GBR using membranes as barriers. However, regardless of the selected technique, the biological foundation and microsurgical principles must be respected and adhered to.

2.1 Ridge Deformity Classifications

Residual deformities have been described and classified using different systems with further subdivisions based on the aspects of deformity and tissue absence.

Horizontal (Class I) defects include those with a loss of the bucco-palatal/lingual contour with an adequate apico-coronal ridge dimensions. Vertical (Class II) defects represent the loss of the apico-coronal tissue contour with adequate bucco-palatal/

lingual ridge dimensions, and Class III defects include deficiency of both apico-coronal and bucco-palatal/lingual dimensions [8].

Another proposed classification relates the severity of the defect to the dimensions of the adjacent ridge. The defects are classified as low (less than 3 mm), moderate (3–6 mm), and advanced (more than 6 mm) [30]. These classifications aid the analysis of intra-arch defects. The surgeon must also consider the inter-arch alveolar ridge relationship during treatment planning to achieve adequate surgical results for prosthetic treatment [31].

The classification systems help the microsurgeon to define the clinical problem and assist further decision-making and treatment planning. The evolution of dental implant therapy has further contributed to the modification of the available classification systems [32] Figs. 2a, b, 3a, b, 4a, b, 5a, b, 6a, b and 7a, b.

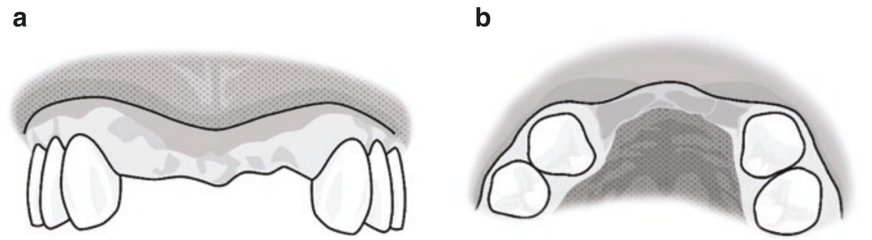


Fig. 2 (**a**) Buccal view of the horizontal defect. (**b**) Occlusal view of the horizontal defect

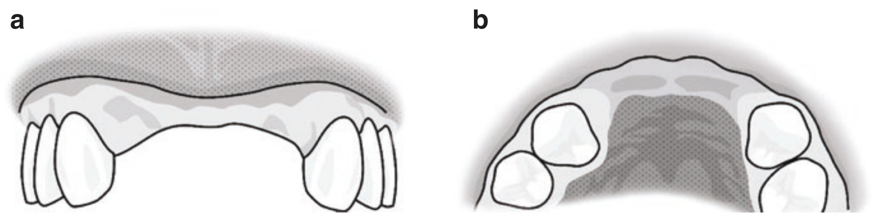


Fig. 3 (**a**) Buccal view of the vertical defect. (**b**) Occlusal view of the vertical defect

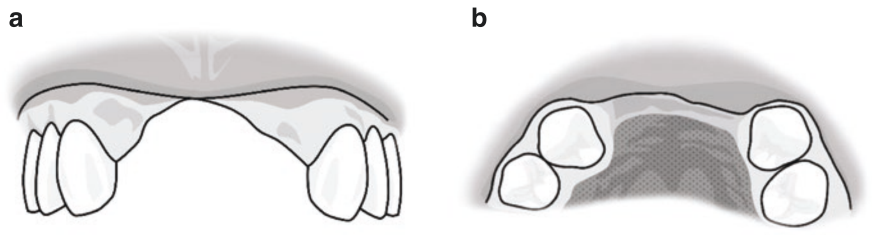


Fig. 4 (**a**) Buccal view of the horizontal and vertical deficiency. (**b**) Occlusal view of the horizontal and vertical deficiency

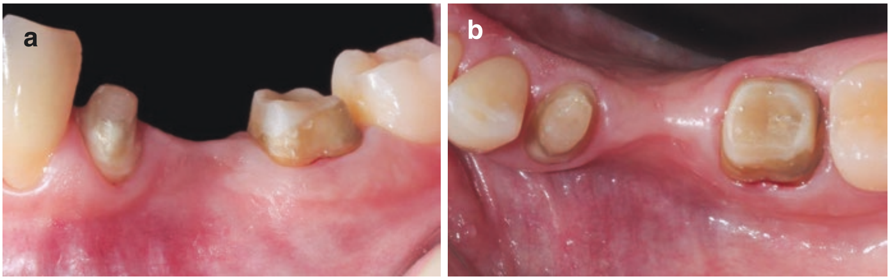


Fig. 5 (**a**, **b**) Buccal and occlusal view of the defect involving loss of buccolingual contour with an adequate apico-coronal ridge dimension

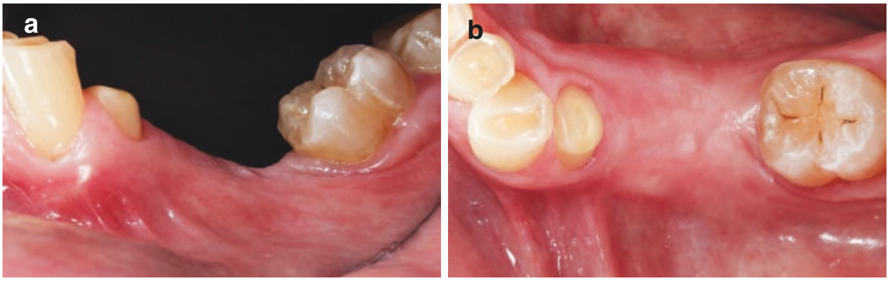


Fig. 6 (**a**, **b**) Buccal and occlusal view of the defect involving loss of apico-coronal tissue contour with an adequate buccolingual ridge dimension

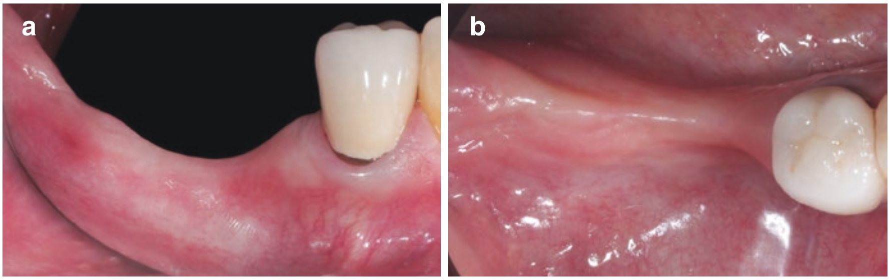


Fig. 7 (**a**, **b**) Defects involving deficiency of both apico-coronal and buccolingual dimensions

2.2 Physiology of Bone Regeneration, Histology, and Participating Cells

Bone regeneration aims to achieve the original structure with a reparative process similar to physiological regeneration but with certain limitations. The minimum conditions required for success include ample blood supply and mechanical stability.

Osseous tissue has an internal layer of endosteum covering the medullar area. It contains osteoprogenitor cells and periosteum, an external fibrous layer of dense connective tissue that has vascular and lymphatic vessels and nerves, in addition to an osteogenic layer formed by several types of cells, elastic fibers, and blood vessels. Cellular richness is capable of promoting growth and bone remodeling. The bone tissue has an intercellular matrix rich in collagen and is also composed of dispersed cells, 25% water, and 25% protein and mineral salts. In osseous tissue, there are five different types of cells which regulate bone formation, maintenance, and repair: osteoblasts, bone-lining cells, osteomorphs, osteoclasts that cover bone surfaces, and osteocytes found within the bone matrix [33–37].

Bone regeneration involves restoration of the lost tissue with cells of the same lineage through osteogenesis, osteoconduction, and osteoinduction through a series of angiogenesis processes and migration and proliferation of undifferentiated cells that transform into osteoblasts. Osteoid production, mineralization, and remodeling occur [33].

There is an intimate relationship between blood vessel formation (angiogenesis) and new bone formation [38]. Bone regeneration significantly depends on these events. Angiogenesis is the physiological process of formation of new blood vessels from the existing vessels, and therefore, the residual bone and periosteum must be treated with special care during surgery; this is possible with enhanced magnification provided by the operating microscope.

2.3 Intra-Operative Visualization of Anatomical Structures

Microsurgery improves soft and hard tissue management, offering better visualization and recognition of anatomical structures during incision placement and flap elevation, where soft tissue integrity is essential. The illumination and magnification can be adjusted according to the needs of the microsurgeon. They aid preservation of the anatomical structures during separation and detachment of tissues, helping to obtain an intact flap of the desired thickness, maintain periosteal integrity, and avoid tissue perforation [22].

2.4 Anatomical Considerations for GBR

Knowledge of the maxillary and mandibular anatomy allows the microsurgeon to locate muscular insertions, neurovascular pathways, spaces occupied by glandular structures, and the oral mucosa. Thus, a thorough understanding of the surgical anatomy provides a solid foundation for the performance of regenerative surgery [39, 40, 41, 43].

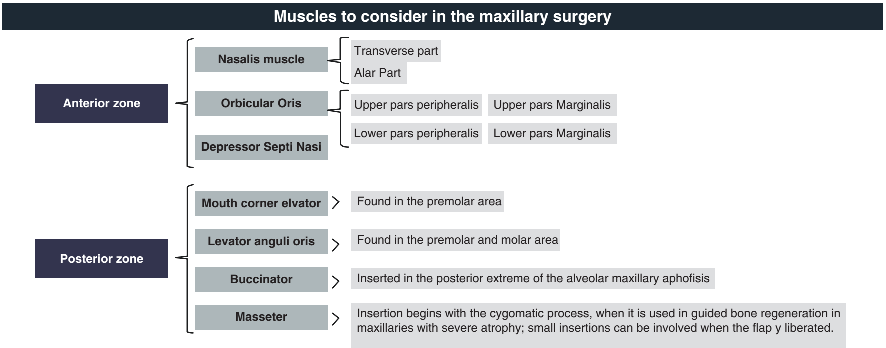
2.4.1 Anatomical Considerations: Musculature

Maxilla

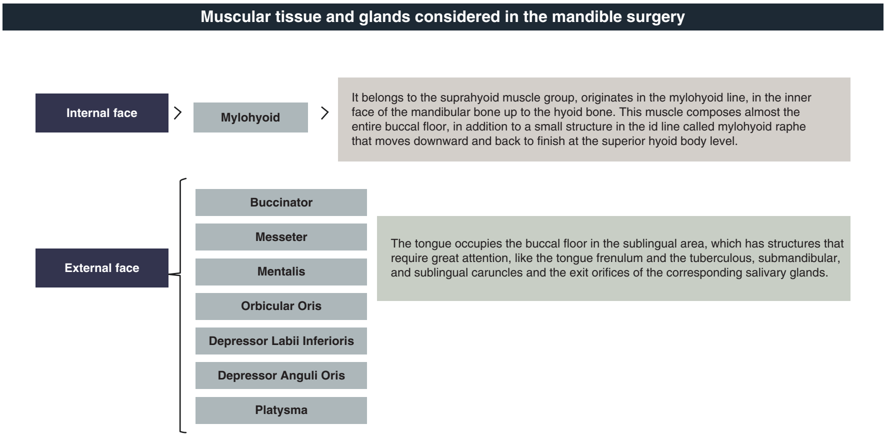
Muscles are attached to the external surface of the maxillae. During GBR, vestibular flap release involves the release of the underlying muscular structures. Using microsurgical techniques, the microsurgeon can perform this action without perforating the mucosa. (Graph 1).

Mandible

The mandible, especially its posterior part, is considered high risk. The clinical experience of the microsurgeon is therefore essential. Microsurgery requires



Graph 1 Muscle anatomical considerations in the maxilla



Graph 2 Muscle anatomical considerations in the mandible

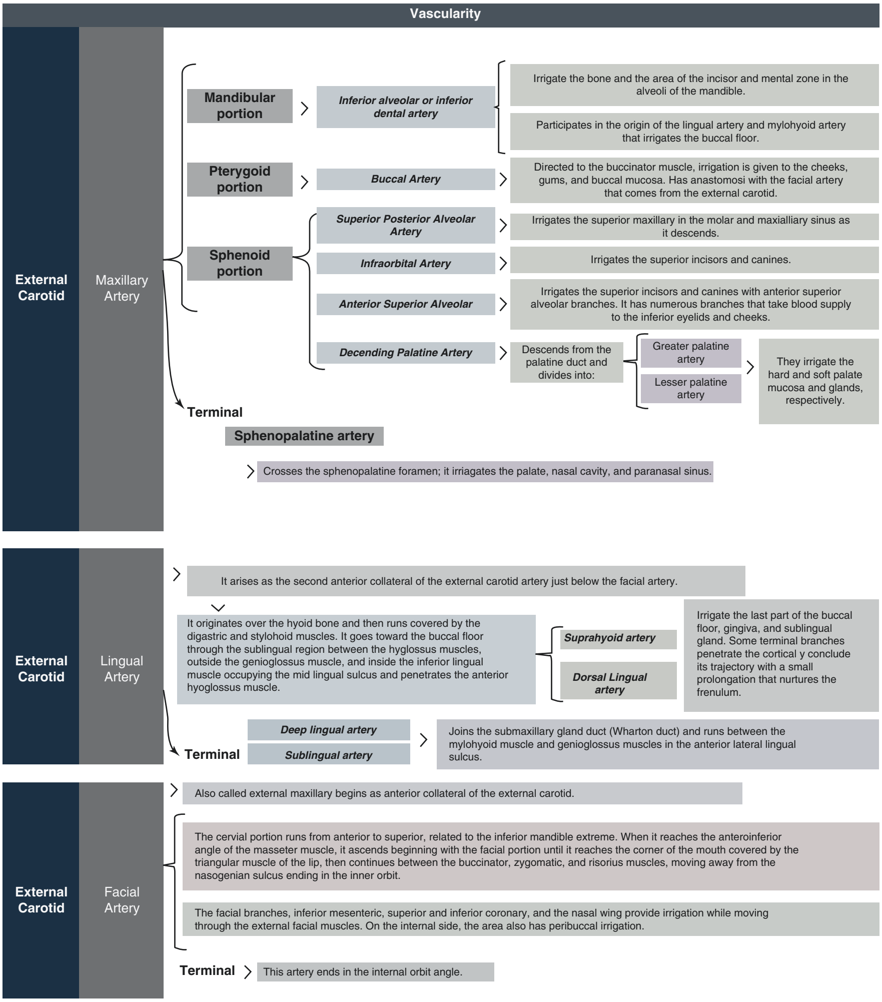
knowledge and training with a steep learning curve; it allows gradual refinement of the surgical procedures.

The floor of the oral cavity, formed by the mylohyoid muscle, requires special consideration as it is a critical area for the release of the lingual flap. Further, a small tendinous structure, called the mylohyoid raphe, is present in the midline.

The tongue occupies the buccal floor in the sublingual area. The structures including the frenulum and its insertions, mandibular tubercles, and openings of the ducts of the corresponding salivary glands require attention during surgery. The muscles inserted on the external surface of the mandible must be considered when releasing the vestibular microsurgical flap. (Graph 2).

2.4.2 Anatomical Considerations: Vasculature

The maxillaries obtain their vascular supply through branches from the external carotid artery. Three of these branches most relevant to maxillary and mandibular GBR microsurgery are: maxillary, lingual, and facial arteries. During regenerative surgery, the microscope, providing illumination and magnification, is useful while



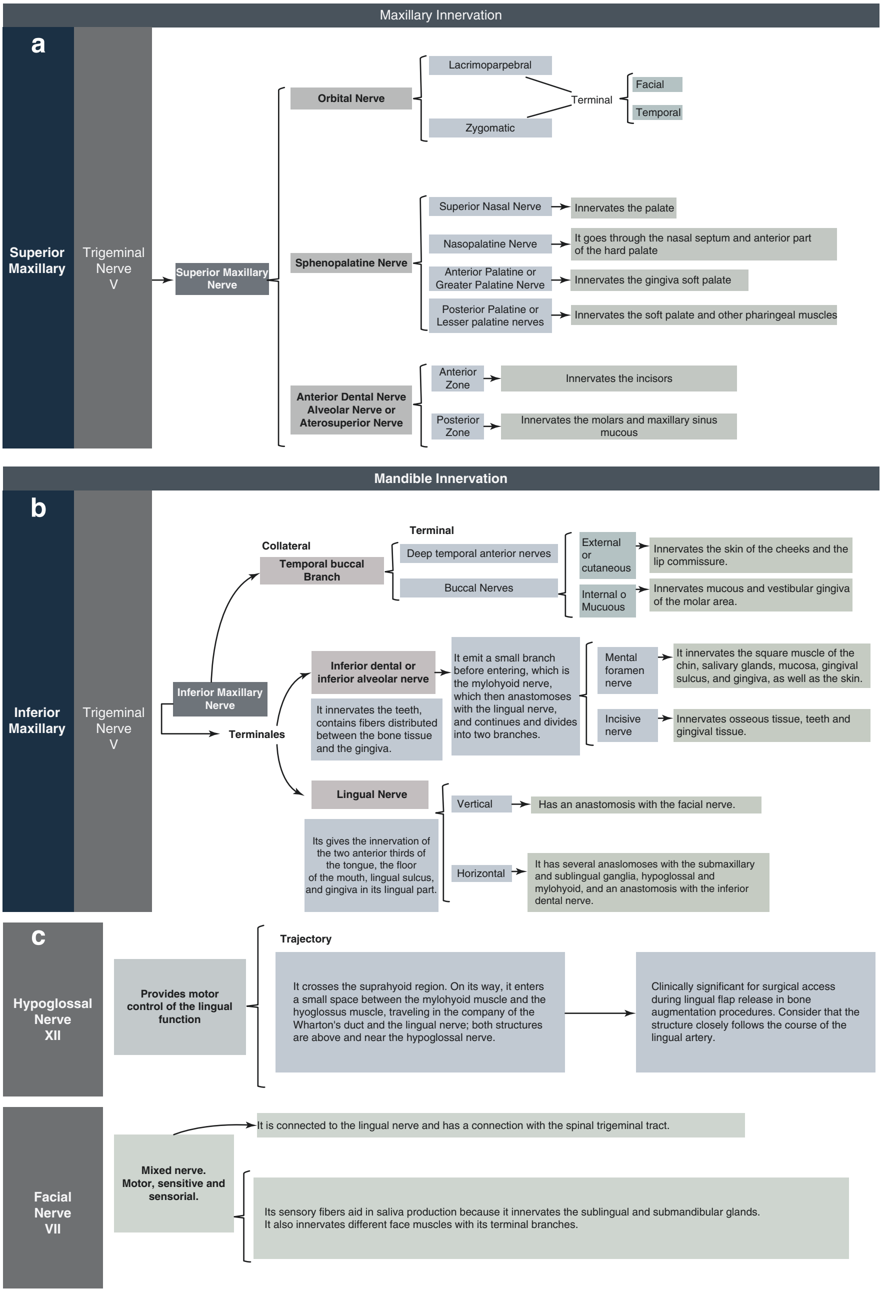
Graph 3 Vascular anatomical considerations in guided bone regeneration

operating close to these vasculature structures and handling flaps and periosteum incisions, preventing surgical complications. (Graph 3).

2.4.3 Anatomical Considerations: Innervation

Prior knowledge of the innervation of the surgical area is necessary, as the preservation of its integrity is essential to preventing complications. The microscope can help visualize areas with severe defects, aiding in the identification of nerve bundles and prevention of intraoperative damage to them.

The trigeminal nerve or V cranial nerve (a mixed nerve) innervates the maxilla and mandible. The use of microscope can enable careful handling of the anatomical structures (Graph 4a–c).



Graph 4 (**a**) Innervation in the maxilla related to guided bone regeneration. (**b**) Innervation in the mandible related to guided bone regeneration. (**c**) Hypoglossal and facial nerve ramifications

3 Microsurgical Soft Tissue Management

Soft tissue management offers numerous advantages in GBR. The knowledge of existing surgical techniques is necessary for refinement of the procedures. Training of the surgeon improves the execution of the techniques and gradually decreases the time taken to perform them. The improvements in the technical results obtained with microsurgical and macrosurgical approaches have been compared, demonstrating advantages in terms of vascularity, healing, and the clinical parameters. The microscopic approach decreases tissue trauma due to the protocols and refined precision because of magnification, which enables improvements in the division and release of the flaps [22].

The selection of the flap design, incisions, materials, and microsurgical instruments differs with each area in the oral cavity. Different degrees of magnification are applied depending on the indication of the surgery. A presurgical appointment for microscopic examination is part of the evaluation and treatment planning process; it is scheduled after non-surgical periodontal therapy with adequate inflammation control criteria that require dental corrections and optimal hygiene. Using different field and augmentation depths, the surgeon observes the tissue quality at the defect site and evaluate the height and thickness of the keratinized tissue, frenulum insertions, vestibular depth, and muscular tone; this data, with the other diagnostic tools, aid in defining the incision area.

3.1 Incision Design

It is necessary to determine the design of the flap before placing the incision to ensure maintenance of flap closure during healing. The planning for flap closure starts even before the placement of dental implants [42]. Thus, determining the type of osseous deficiency, selection of the bone augmentation technique, anatomic references, bone peaks adjacent to the defect, estimated bone gain, and degree of anticipated difficulty of the surgical procedure is crucial.

The primary incision (crestal incision) is placed crestally, in a mesio-distal direction at the edentulous site. The surgical scalpel is held firmly, perpendicular to the tissue and a single lightly penetrating incision is placed, touching the bone along the incision line. A secondary incision is repeated over the first, ensuring penetration of the scalpel through the complete thickness of the tissue, which protects its integrity with the inner face. The surgeon makes the main incision with a 15C blade (Hu-Friedy Mfg. Co., LLC Chicago, IL, USA) using microsurgery blades MB64 and MB67 (Hu-Friedy Mfg. Co., LLC Chicago, IL, USA) in the areas close to the teeth, extending as intracrevicular incision on the buccal and palatal/lingual aspects of the adjacent teeth. The surgeon begins the incisions on the distal aspect of the most distal tooth included in the flap design, moving mesially. Using angled microsurgery blades ensures a complete cut while placing intracrevicular incisions. This area has complicated access, and indirect vision is necessary to ensure incision integrity.

The surgeon places the principal or crestal incision in keratinized tissue. This incision will depend on the position of the center of the mandibular ridge, but exceptions may occur. In the maxilla, it is recommended to place the incision slightly buccally. This is because the palatal mucosa is firmly adherent, while the lingual mucosa of the mandibular ridge is associated with movable mucosa and muscular tissue that favors passive advance [42, 43].

Secondary incisions (releasing) allow visibility and accessibility to instruments and increase flap mobility, contributing to tension-free closure [43]**.** The extension of the horizontal releasing incision improves access and, if using non-resorbable membranes, helps avoid vascular compromise [44]**.** In the edentulous areas, releasing incisions must be placed 8–10 mm distal to the membrane borders, up to 2 mm distal to the retromolar pad. It is preferable to place the vertical incisions one or two teeth away from the defect site on the buccal aspect and two to three teeth away from the lingual/palatal site; therefore, the length of the flap varies based on the case and region of interest. An example of the horizontal length of the flap being greater occurs when surgeons do not place vertical releasing incisions.

The same criteria apply to the vertical releasing incisions at mesial, distal, or both sides of the area requiring augmentation. The incision should be placed at least one or two teeth away from the surgical site to protect the underlying bone and the vascularity of the flap. In adjacent buccal areas with teeth, the bone augmentation area must be distant in at least one or two teeth, and the complete incision is performed with a new 15C blade or with a microsurgical scalpel held perpendicular to the underlying bone. The trajectory begins at the gingival margin at the tooth angle, avoiding the interdental area or midsections with radicular prominences; [45] this incision is placed to achieve exact repositioning and may require greater magnification because the visual field should be more localized to improve precision. The vertical incision may have a hockey stick form initially, involving papillae, continuing straight with a total thickness [46]**.** Another variation includes a vertical incision placed to produce a surgical papilla positioned coronally, followed by a partial incision perpendicular to the tissue, without reaching the bone. The microsurgeon places the blade perpendicular to the gingival margin, forming the papilla diagonally with a slight angle to continue with the releasing incision of total thickness beyond the mucogingival line (video). In the posterior areas of the mandible, the distal releasing incision is made, moving obliquely toward the mandibular branch and ending lateral to the flap so as to preserve the lingual nerve.

On the lingual/palatal aspects, we place mesial and distal vertical releasing incisions in areas distant from the augmented site. The criteria are determined according to the requirement of the surgical site and the discretion of the microsurgeon since it involves increased difficulty [41, 45]. Videos 2, 3, 4 and Fig. 8a–e.

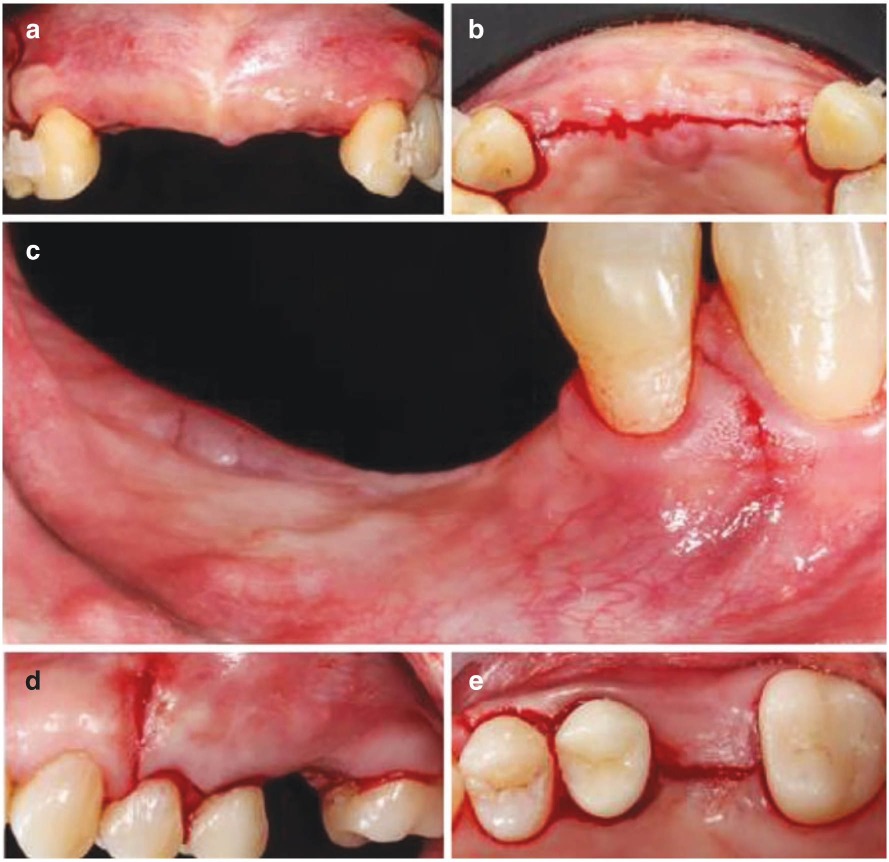


Fig. 8 (**a**–**e**) Primary (crestal) and secondary (releasing) incisions

3.2 Decision to Place Vertical Incisions

Vertical releasing incisions aid the coronal positioning of the flap and provide the visibility and accessibility necessary for the appropriate placement of the graft and membranes, also allowing the procurement of autologous bone.

Vascularity is an essential aspect of flap nutrition; a vertical incision could interrupt the vascular supply gingiva, the mucous vessels' microcirculation trajectory, and the periosteum. However, the microsurgical adaptation will aid revascularization, allowing for the incised tissue to heal rapidly (Video 5).

3.3 Steps in Flap Releasing: Layered Releasing Incision, Linear Incision, and Selectively Releasing Incision

3.3.1 Microsurgical reflection

It is described as *initial separation*, or the detachment of the adhered zone on the buccal and lingual/palatal sides. It is secondary to the periosteal incision in the buccal and lingual areas and releasing of muscular attachments in the upper and lower buccal areas and lower lingual areas. It is necessary to have magnification for the visualization of the instrument trajectory. In certain situations, the surgeon may take a closer look to perform adjustments. Additionally, adequate irrigation is essential to keep the tissues in the surgical area clean and hydrated, in addition to a microsurgical ejector with effective suction.

The surgeon makes the *initial separation* in the flap reflection, carefully elevating the periosteum with a microsurgical periosteal elevator throughout the length of the incision and firmly separating the adhered tissue. This separation is extended beyond the vertical and horizontal dimensions of the defect, on both the facial and lingual/palatal aspects.

For the secondary periosteum incision and the release of muscle fibers on the buccal aspect in the maxilla, the microsurgeon must take into account the anatomical areas at risk and move the blade in a coronal-buccal direction Fig. 9a–c The procedure is performed with a 15C scalpel starting from the distal areas, moving mesially along the length of the flap. The muscle fibers should be separated until significant flap mobility is achieved. The released extension is verified by advancing coronally until it reaches the occlusal aspect.

The posterior areas allow limited visibility. The microscope therefore offers excellent safety while performing the periosteal incision for flap liberation, allowing detachment of the flap with a single cut to prevent tissue damage in such areas Video 6 and Fig. 9d–f. The anterior area receives equal treatment, with the periosteal incision extending from side to side, connecting both vertical incisions. When the flap does not advance in both situations, additional subperiosteal cuts are necessary to separate the elastic fibers using microsurgery tissue scissors, and a periosteal instrument is used in a coronal pulling motion to separate the elastic fibers.

There is a compromised zone on the mandibular buccal aspect near the premolars by the mental foramen. The location of the foramen must be identified, and the periosteal incision should be placed cautiously using the inverse side of the scalpel blade, drawing a curve surrounding and continuing at the linear incision to protect the site during reflection and minimize the risk of paresthesia Fig. 10a–c.

The surgeon separates the muscle fibers in the lateral and bucco-coronal directions on the buccal aspect. In this particular area, magnification enables good execution Video 7.

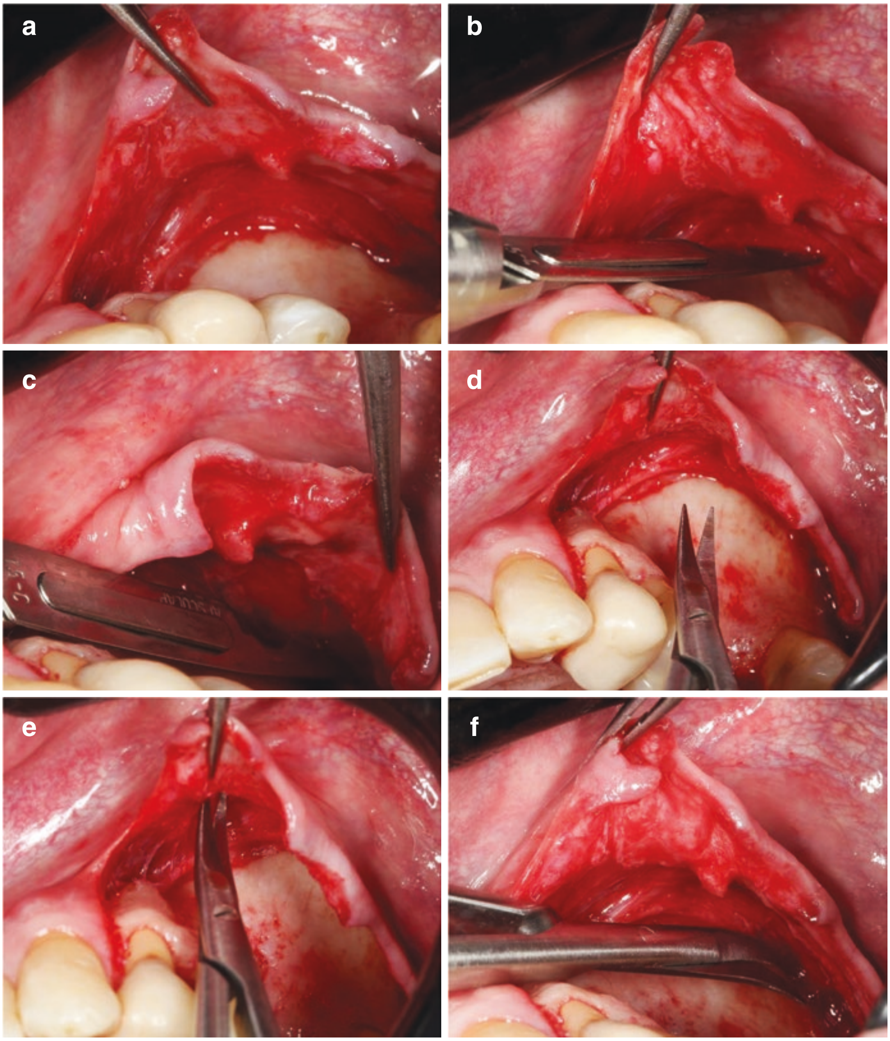


Fig. 9 (**a**–**f**) Secondary periosteal incisions and release of muscle fibers

The lingual area is considered high risk because of the anatomical structures and possible complications [47]**.** A microscope allows the observation of different tissues with a clear definition. Magnification aided by the coaxial light offers a clear image of the insertion of the mylohyoid for correct dissection and allowing careful manipulation around the neuro-lingual sublingual artery branching from the lingual artery in this area.

The molar area is located at the highest position of the buccal floor, closer to the neurovascular bundle. Thus, the mylohyoid muscle fibers are released using a blunt instrument with a soft movement in the coronal direction extending mesially. There

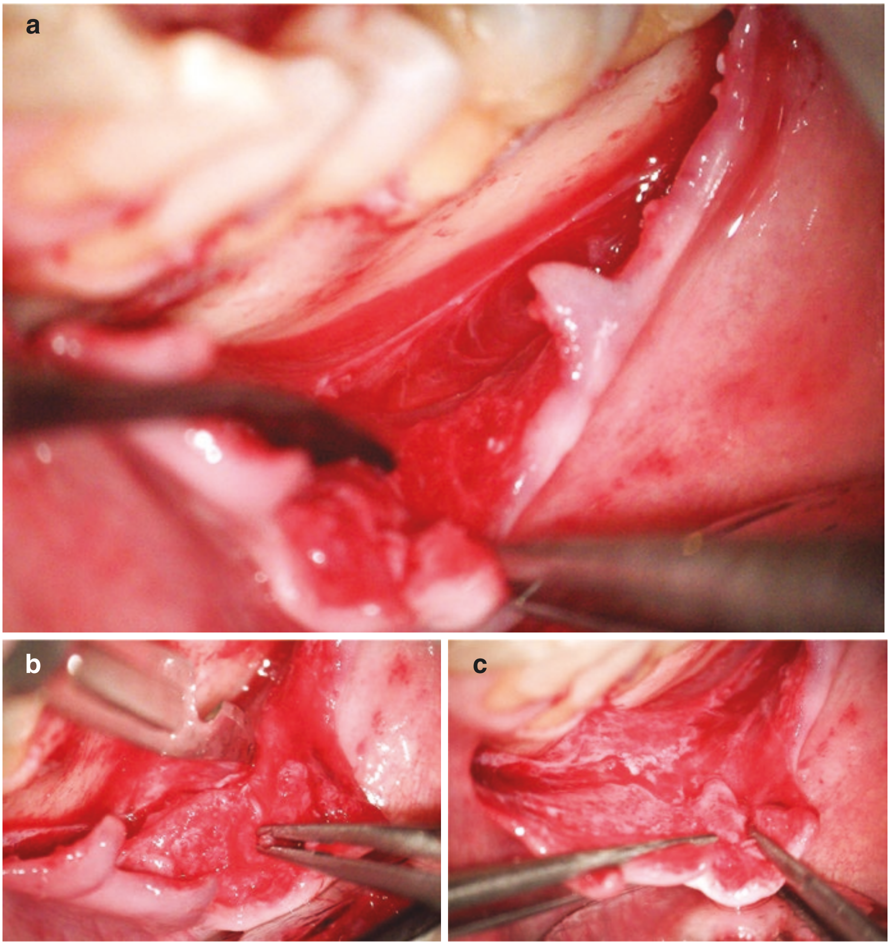


Fig. 10 (**a**–**c**) Secondary periosteal incisions and release of muscle fibers in the mandibular premolar region

is a deep muscular insertion at the premolar level, and the surgeon may be able to release it with a soft sweeping motion in the coronal direction [41, 44].

Therefore, the effective release of the lingual muscle fibers will compensate for the limited release of the buccal flap in the mental nerve area, allowing flap closure [44, 47].

Another option for lingual flap release in the posterior mandibular region is to reflect the flap using a wet gauze positioned between the osseous and the soft tissue, with moderate pressure over the gauze [48] (Video 8). Then, the mylohyoid muscle fibers can be gently separated, using posterior sweeping movements with a blunt instrument [48]. The adequate release of muscle fibers using any technique allows to obtain hemostatic control on reflection of the flap, which is another benefit of microsurgery and having support when inexperienced at high-risk procedures. The use of microscope significantly improves the surgeon's performance.

The palatal tissue does not have elastic properties. Therefore, its integrity must be preserved during the separation. Inappropriate manipulation can damage the tissue, complicating closure. The anatomical situation contributes to the increased difficulty. Thus, the surgeon must treat the anterior and posterior zones differently. The buccal tissues move palatally during closure because the density and insertion of the palatal mucosa prevents its displacement. A double internal incision can be made on the palatal area to allow the rotation of the underlying connective tissue in a coronal direction to aid flap closure [43, 48] (Figs. 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22).

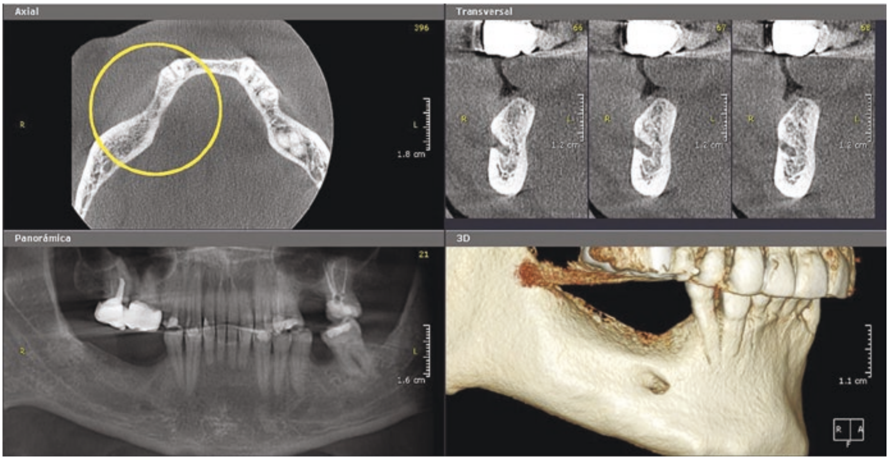


Fig. 11 Axial, transverse, panoramic, and 3D cone beam images showing apico-coronal and buccolingual deficiencies in the right posterior region of the mandibular alveolar process

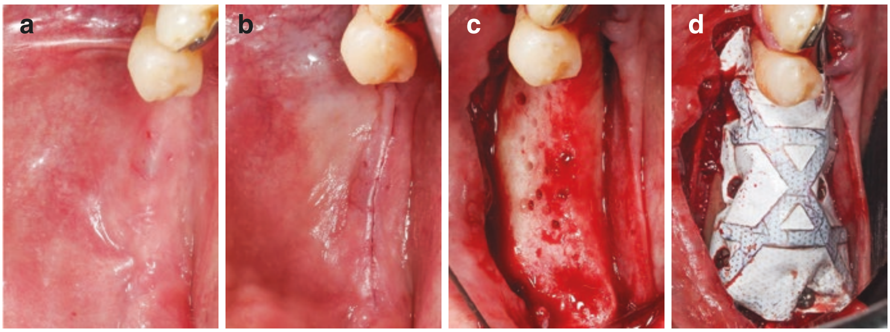


Fig. 12 Occlusal microsurgical guided bone regeneration in the right posterior mandible. (**a**) Preoperative image. (**b**) Primary incision (supracrestal). (**c**) Buccal and lingual microsurgical release and bone screening. (**d**) Graft placement (autologous and deproteinized bovine bone and placement of a nonabsorbable PTFE ™ dense, titanium-reinforced Cytoplast ™ membrane, with Pro-fix ™ fixation system screws)

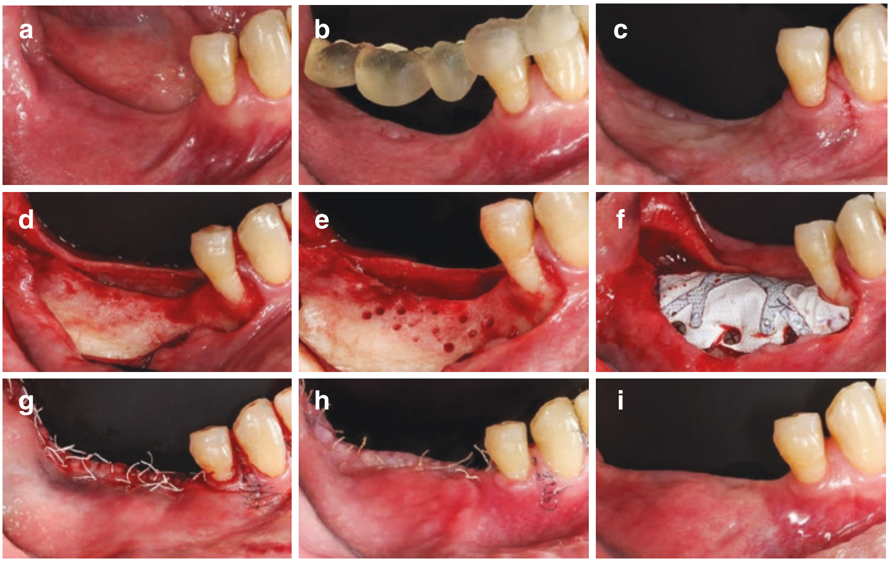


Fig. 13 Intraoral microsurgical guided bone regeneration of the right posterior mandible. (**a**) Initial image of the defect in the posterior right mandible. (**b**) Surgical guide. (**c**) Buccal view: primary (supracrestal) and secondary (vertical) incisions. (**d**) Buccal and lingual microsurgical release. (**e**) Bone screening. (**f**) Buccal view: graft placement (autologous and deproteinized bovine bone and placement of cytoplast™ dense non-absorbable PTFE™ membrane reinforced with titanium, with Pro-fix™ fixation system screws). (**g**) Flap closure at the primary incision with horizontal mattress sutures and individual interrupted knots, complemented with individual microsurgical knots for closure along the vertical incisions. (**h**) After 2 weeks of healing. (**i**) After 6 weeks of healing

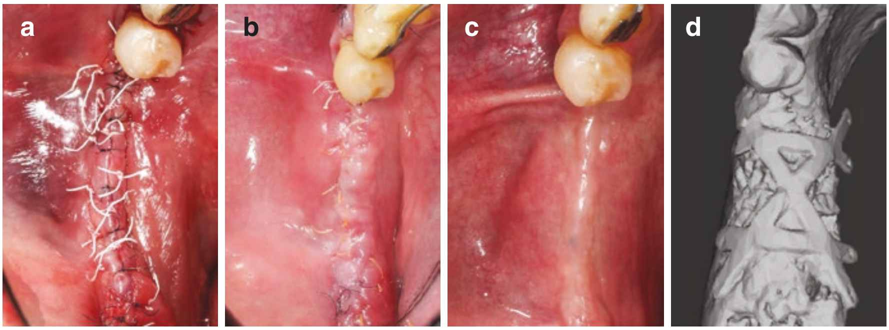


Fig. 14 Occlusal microsurgical guided bone regeneration of the right posterior mandible. (**a**) Flap closure at the primary incision with horizontal mattress sutures and individual interrupted knots, complemented with individual microsurgical knots. (**b**) Occlusal view after 2 weeks of healing. (**c**) Occlusal view 6 weeks into healing. (**d**) Digital imaging for guided surgical treatment planning

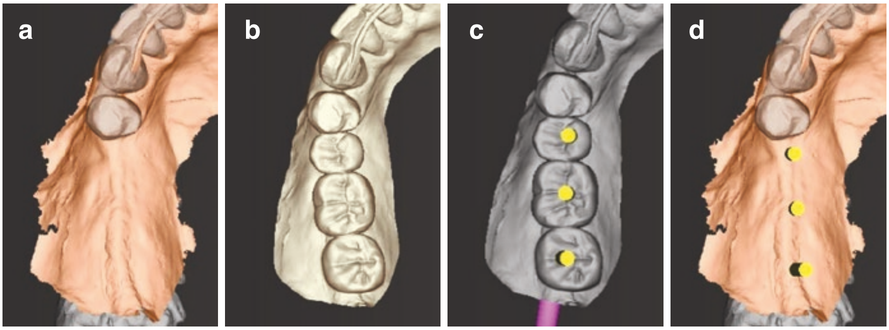


Fig. 15 (**a**–**d**) Digital imaging for guided surgical treatment planning using coDiagnostiX™

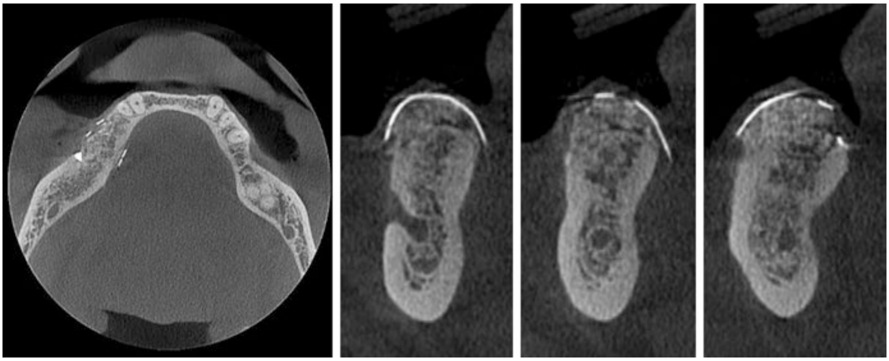


Fig. 16 Axial, sagittal, and 3D cone beam images showing an apico-coronal

Fig. 17 Buccolingual gain in edentulous alveolar processes of the right posterior mandible and treatment planning using coDiagnostiX™

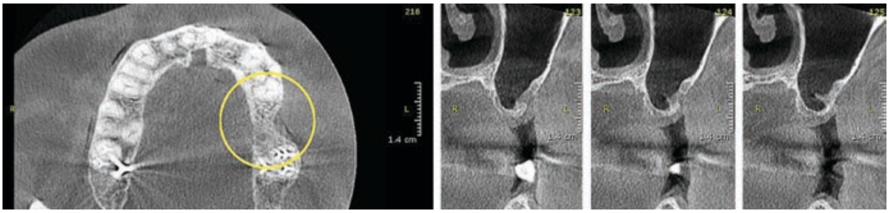


Fig. 18 Axial cone beam images showing bone loss in the bucco-palatal direction in the posterior maxilla, sagittal images with advanced vertical loss, and collapse of the maxillary sinus

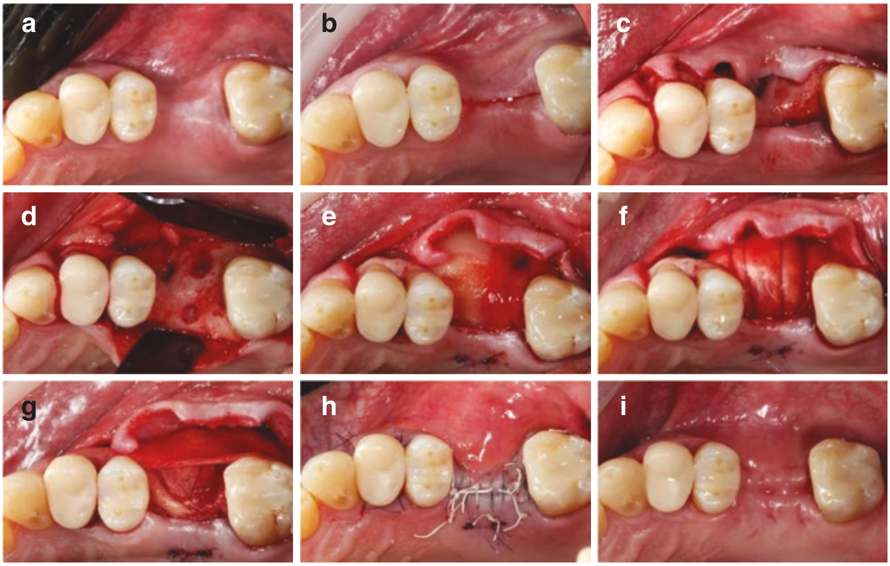


Fig. 19 Microsurgical guided bone regeneration. Occlusal views of the left posterior maxillary dentition. (**a**) Preoperative image. (**b**) Primary incision (supracrestal). (**c**) Buccal and palatal microsurgical release. (**d**) Occlusal view of receptor bed showing bone defects. (**e**) Placement of the autologous membrane of leucocyte and platelet-rich fibrin (L-PRF) on a mixture of xenograft (inorganic bovine Bio.Oss® cancellous bone substitute) and allograft Puros® cancellous particulate allograft bone. (**f**) Occlusal view of the long-lasting absorbable membrane (botiss Jasonz®), with horizontal suspensory sutures using absorbable Polyglycolic acid and caprolactone 5-0 (RESORBA®, Glycolon™ Manufacturing) sutures. (**g**) Management of soft tissue on regeneration using an allograft (acellular dermal matrix) placed before flap closure. (**h**) Flap closure at the primary incisions with horizontal mattress sutures and individual interrupted knots, complemented with individual microsurgical knots. (**i**) Occlusal view 2 weeks into healing

Fig. 20 Intraoral microsurgical guided bone regeneration. Buccal views of the left posterior maxillary dentition. (**a**) Initial image of the horizontal and vertical defect in the upper right first molar area. (**b**) Buccal view: crestal and vertical releasing incisions. (**c**) Elevation of a full-thickness mucoperiosteal flap reveals the receptor bed with bone fenestration communicating with the maxillary sinus. (**d**) Placement of xenograft (Bio.Oss® bovine inorganic spongious bone substitute), cancellous bone allograft (Puros®), and autologous membrane fibrin rich in crushed platelets (L-PRF) in a uniform mixture with adaptation to the bone defect before placement of the membrane. (**e**) Placement of an autologous membrane of L-PRF. (**f**) Placement of a long-lasting absorbable membrane (botiss Jasonz®). (**g**) Membrane fixation with horizontal suspensory sutures using resorbable suture of polyglycolic acid and caprolactone 5-0 (RESORBA®, Glycolon™ Manufacturing)

Fig. 21 (**a**–**e**) (**a**) The extension and release of the flap are verified by advancing it coronally. (**b**) Placement of an autologous membrane of leucocyte and platelet-rich fibrin (L-PRF) on the regenerative materials. (**c**) Soft tissue management by placement of an allograft (acellular dermal matrix) before closure and fixation with microsurgical (8-0) polyglycolic acid sutures. (**d**) Flap closure at the primary incisions with horizontal mattress sutures and individual interrupted knots, complemented with individual microsurgical knots for closure along the vertical incisions. (**e**) Buccal view 2 weeks postoperatively

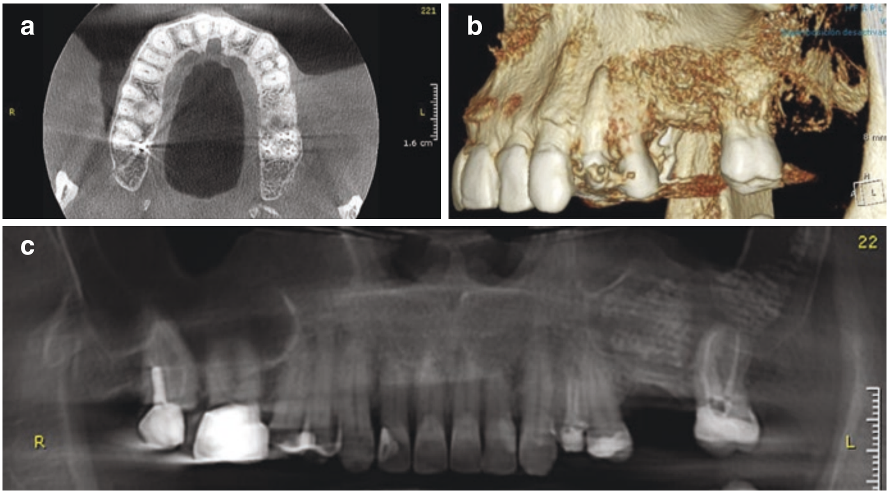


Fig. 22 (**a**–**c**) Cone beam images show the results of guided bone regeneration, with ridge gain in both directions and bone gain following sinus elevation

4 Special Considerations in Material Selection and Placement

4.1 Selection and Management of Regenerative Materials and Their Combination in Microsurgery

Impeccable management of regenerative materials is essential when working with microscopic techniques. The magnification and resulting optimum accuracy allow compliance with the strict biological principles for manipulation, autologous bone collection, mixture preparation, and membrane fixation. Material selection depends on the operator's approach to scientific evidence. The purpose of regenerative materials is to induce formation of high-quality bone tissue that allows osseointegration of the dental implants intended for masticatory use [49].

4.2 Autologous Bone Graft, Allografts, Xenografts, and Membranes

Intraoral autologous bone is considered the best grafting material, and its properties comply with the primordial biological requirements of regeneration, such as osteogenesis, osteoconduction, and osteoinduction [50] Fig. 23a. A donor site is required, and the graft is procured in the particulate form or as a block, depending on the selected technique. The posterior mandible is an ideal location to obtain the graft. However, there are also tuberosities, symphysis, mandibular tori, and peripheral supporting bone. Some instruments and attachments are ideal to effectively

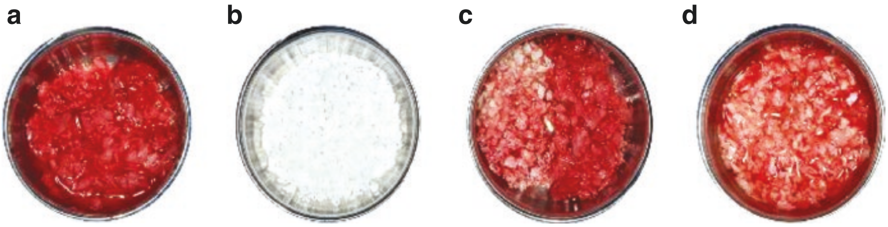


Fig. 23 (**a**–**d**) (**a**) Intraoral autologous bone graft. (**b**) Xenograft: inorganic bovine-mineral tissue, deproteinized and cancellous (Bio.Oss®) substitute for natural bone. (**c**) Mixed graft: mixture of autologous bone graft and xenograft inorganic bovine Bio.Oss®. (**d**) Sticky bone: mixture of autologous bone graft and xenograft inorganic bovine (Bio.Oss®) with crushed platelet-rich autologous membrane fibrin (L-PRF)

obtain particulate bone. Microscopic surgery aids in this approach by protecting the adjacent tissue and providing visibility, which helps to control the quantity of the bone material obtained. The experience of the technician is an essential factor to consider.

Autologous bone is the gold standard in bone regeneration. Nevertheless, literature also describes other bone-filling material options that prevent donor-site morbidity and are used in different clinical situations.

4.2.1 Xenografts

There is scientific evidence that supports the use of inorganic bovine bone as a substitute for natural bone. It has osteoinductive properties and provides a scaffold that aids bone formation with its orientation and structure. It is used for horizontal and vertical bone augmentation, preserving bone volume in the long term. Technological advancements have helped to develop this graft to facilitate biological interactions and subsequent bone regeneration [51]. The inorganic bovine-mineral tissue is deproteinized and cancellous, with a form and surface that favors contact with the blood clot and has internal interconnected channels that facilitate vascular and cellular growth Fig. 23b.

4.2.2 Allografts

Allografts obtained from a human cadaver are mineralized and demineralized, depending on the processing of the graft. They are used for GBR due to the osteoconductive property of the mineralized cancellous graft. Allografts have a high regenerative capacity. However, long-term bone gain requires further investigation, especially in relation to the stability of vertical augmentation.

4.2.3 Mixed Grafts

Hard evidence demonstrates that combining graft materials in different proportions, especially autologous and deproteinized bovine bone, offer satisfactory results, with predictable bone regeneration and high success rates for both horizontal and vertical bone augmentation [52–54]. Videos 9, 10, 11 and Figs. 23a–d and 24a, b.

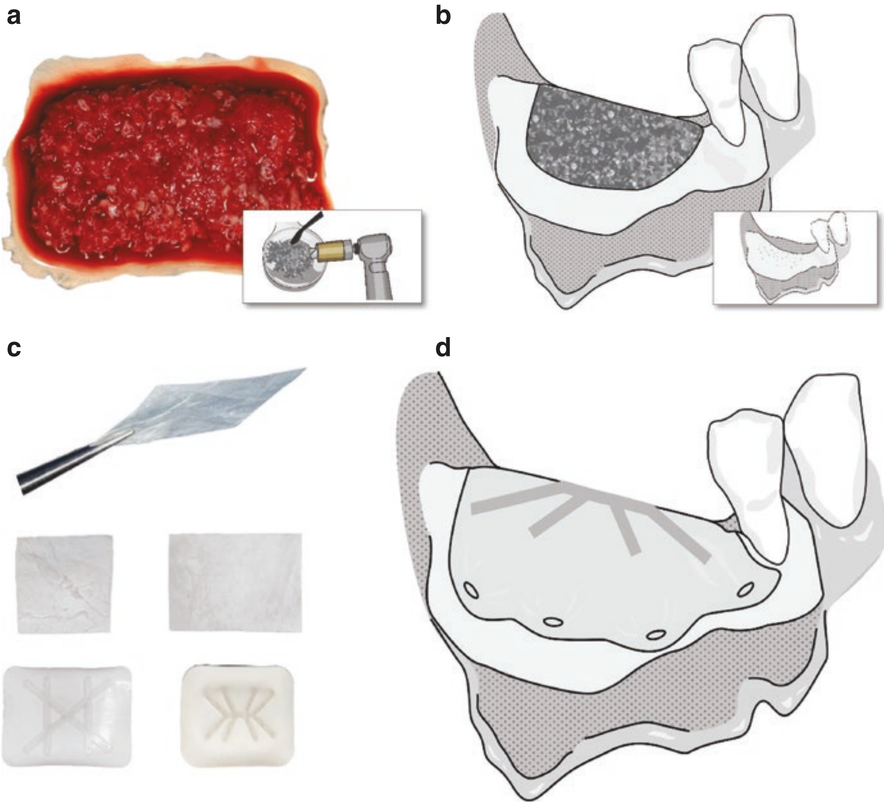


Fig. 24 (**a**.1) Sticky bone: mixture of autologous bone graft and xenograft inorganic bovine (Bio. Oss®) with crushed platelet-rich autologous membrane fibrin (L-PRF). (**a**.2) Trephine used to obtain autologous bone and its careful handling. (**b**.1) Placement of the graft (sticky bone) in the recipient bed. (**b**.2) Bone screening before graft placement. (**c**.1) Membranes can be resorbable and non-resorbable. Their selection is based on the defect morphology. (**d**) Example of fixation of a nonabsorbable membrane (nonabsorbable dense PTFE™ membrane reinforced with titanium with Pro-fix™ fixation system screws)

4.3 Use of Resorbable and Non-resorbable Membranes

Successful bone augmentation depends on four essential biological principles: wound closure, angiogenesis, maintenance, and wound stability [1].

The use of membranes in GBR depends on the principle of the exclusion of unwanted cells at the grafted site, creating a protected space for the blood clot-organized area, preventing collapse, and allowing migration of cellular osteoprogenitors and vessels, facilitating osteopromotion [4, 55, 56]. Membranes can be resorbable or non-resorbable and designed for simple management; they integrate with the surrounding tissue and allow nutrient permeation. The selection of the membrane depends on the size, morphology, and the severity of bone deficiency Fig. 24c, d.

Resorbable membranes with high biocompatibility integrate with tissues, improving vascularity for bone formation. They are easy to manage and are used in combination with particulate grafts in horizontal defects. There are different types of resorbable membranes: synthetic membranes, crosslinked collagen membranes with higher resorption times, and native collagen membrane with rapid biodegradation. Although indicated for horizontal defects, resorbable membranes can be used in unusual vertical defects, minimizing exposure risks [41, 53, 54].

Surgeons also use **non-resorbable membranes** for vertical augmentation treatments, where greater stability is required to support the graft. They maintain their structural integrity, require re-entry for removal, are biocompatible, and must be adequately adapted because they are susceptible to exposure complications. The standard membrane is composed of polytetrafluoroethylene (PTFE), high density or expanded. Titanium reinforcements are adequate for moderate to severe vertical augmentation [52, 55, 57].

4.4 Use of Dermis Allograft as Membrane

The use of acellular dermal matrix has been accepted for augmentation of soft tissues and is used in GRB to complement membranes for improvement of the soft tissues or as an occlusive membrane Videos 12, 13 and Fig. 25a–c. They offer rapid revascularization and cell growth and have a traditional method of fixation with tacks or suspensory sutures with additional microsurgical sutures to the

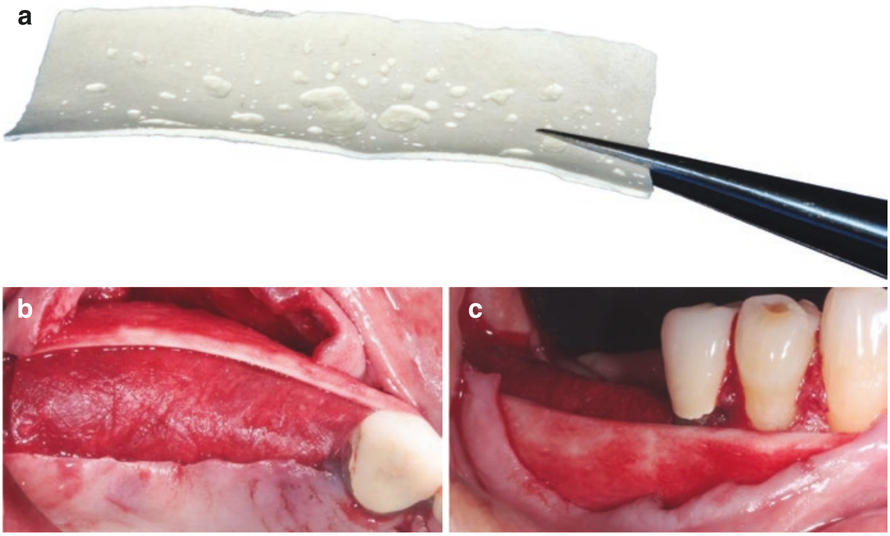


Fig. 25 (**a**) Acellular dermal matrix (AlloDerm™) for soft tissue application (**b**, **c**). Occlusal and buccal view: placement of the membrane for soft-tissue management in regenerative therapy

periosteum. Its use as a membrane has satisfactory results, with improved cicatrization patterns. However, further research is needed to support these observations [58, 59].

4.5 Use of Biologics

Biological mediators have received great acceptance in regenerative therapy. Different autologous blood concentrates increase the healing response for favorable results. Leucocyte and platelet-rich fibrin (L-PRF) is a commonly used mediator. It is a second-generation platelet concentrate used as a bone augmentation therapy adjunct. It offers continuous growth factors and other bioactive substances that protect and stimulate the surgical site; it can be used as a membrane, plug, or exudate, promoting tissue healing and imparting antibacterial effects [60–62]. The L-PRF has an application in periodontal therapy, in microsurgical bone augmentation, because of its biological properties. For example, the membranes can be sutured to cover grafts or regenerative materials, enabling close contact with the flap periosteum. It also protects the graft from complications, such as exposed membrane, and aids in soft tissue healing. The microsurgical suture preserves the integrity of the L-PRF membrane when fixed in the outermost area of the wound or bone clot during the first days of healing, and is used with composite bone grafts and *sticky bone*, among others, to offer stability and biological properties Videos 14, 15, 16 and Figs. 24a, 26e, 27c, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37(e, g), 38, 39.

Other growth factors have gained attention in recent years. Development of tissue engineering has contributed to the use of biological factors that stimulate tissue formation in bone regeneration therapy. The safety and efficiency of the highly purified bioactive protein rhPDGF-BB (purified human platelet-derived growth factor) combined with an osteoinductive matrix (beta-tricalcium phosphate) GEM21S®

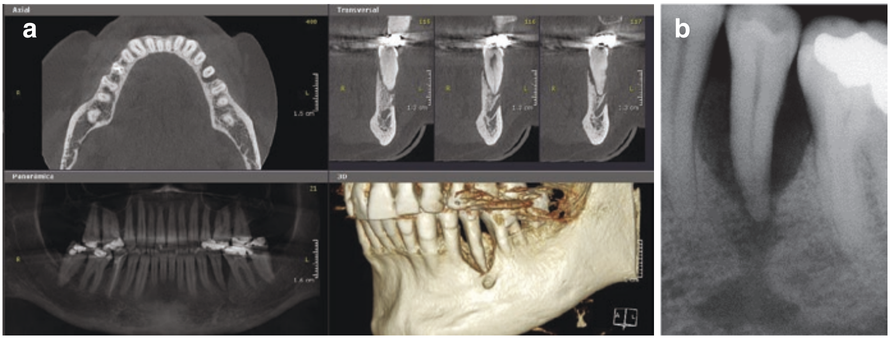


Fig. 26 (**a**) Axial, transverse, panoramic, and cone beam 3D images showing a severe vertical and horizontal defect in the lower left second premolar. Progressive bone loss is present close to the mental foramen. (**b**) Periapical radiograph shows the apical extent of the bone defect shaped like an hourglass

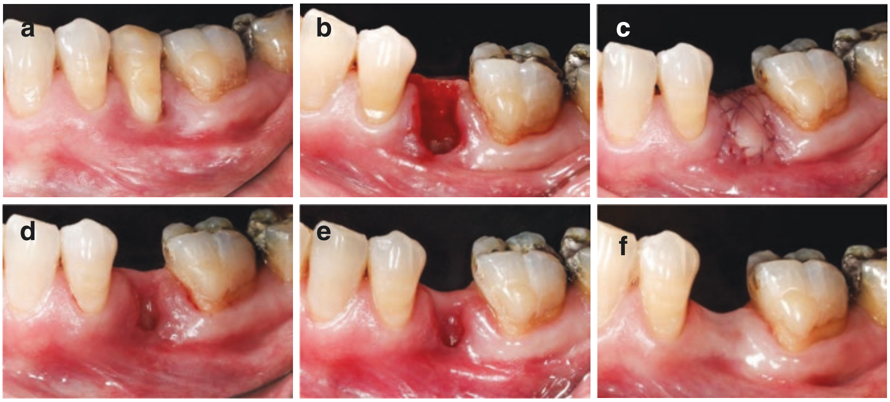


Fig. 27 Extraction of the lower left second premolar extraction and use of biological mediators with microsurgical techniques. (**a**) Preoperative image. (**b**) Result of the atraumatic extraction. (**c**) Fibrin plugs and membranes rich in leukocytes and platelets (L-PRF) are introduced into the alveolus and stabilized with a microsurgical suture. This helps preserve the integrity of the L-PRF membrane, maintaining its biological properties and promoting healing. (**d**–**f**) Buccal view two, four, and eight weeks into healing

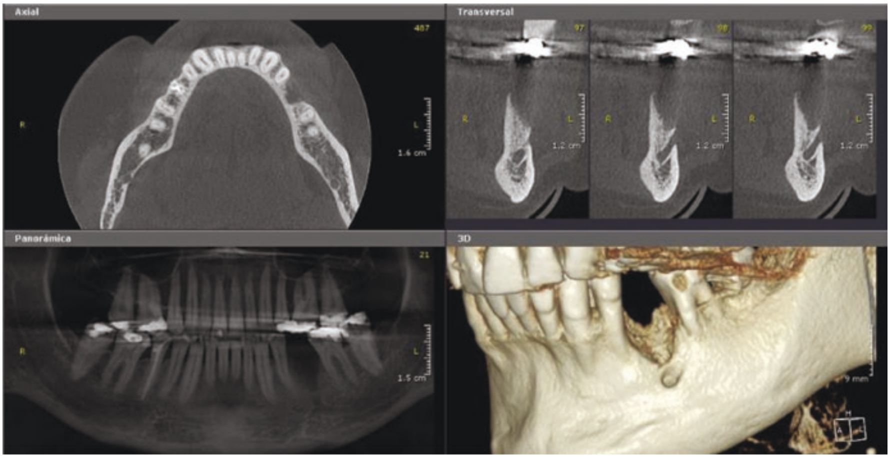


Fig. 28 The axial, transversal, panoramic, and cone beam 3D images show the residual post-extraction defect

Lynch Biologics, Franklin, TN 37064, has been demonstrated to cause a significant increase in regeneration, proliferation, and migration of osteoblasts and other periodontal cells.

The autogenous bone mixed with inorganic bovine bone-derived mineral (ABBM) and rhPDGF-BB has demonstrated significant potential for bone regeneration [63–65].

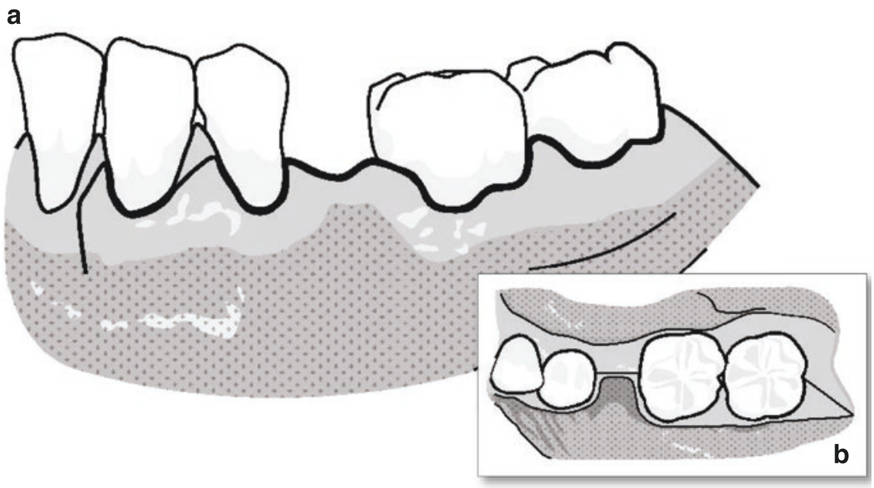


Fig. 29 (**a**, **b**) Design of the flap: primary incision and horizontal and vertical releasing incisions

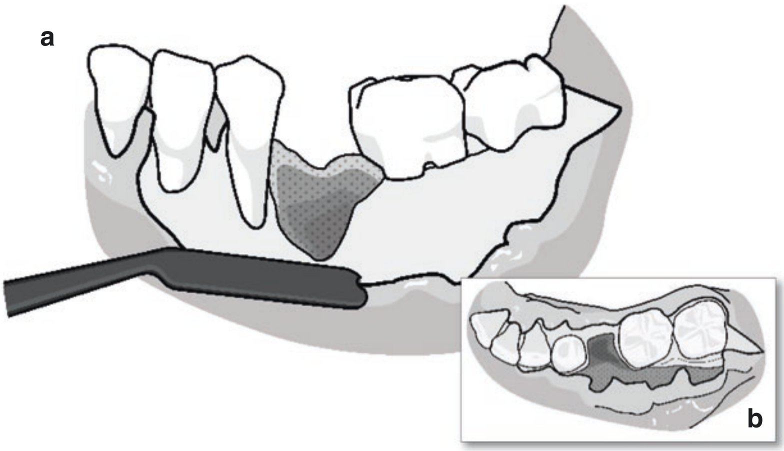


Fig. 30 (**a**, **b**) Full-thickness buccal and lingual flaps elevated to expose the deficient ridge

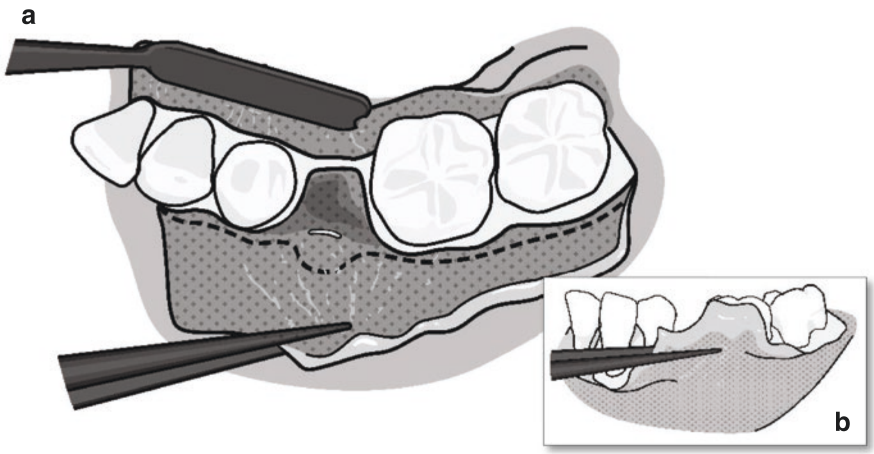


Fig. 31 (**a**, **b**) The drawings represent the line of the periosteal incision protecting the mental foramen area and the flexibility of the buccal flap after flap release

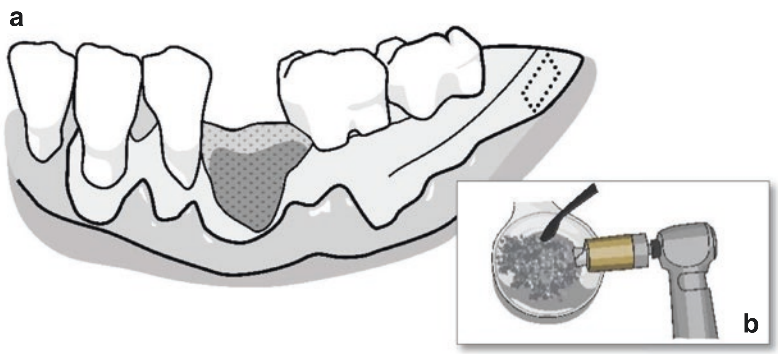


Fig. 32 (**a**, **b**) Representation of bone extraction from the mandibular ramus, which is an ideal donor site for autologous graft

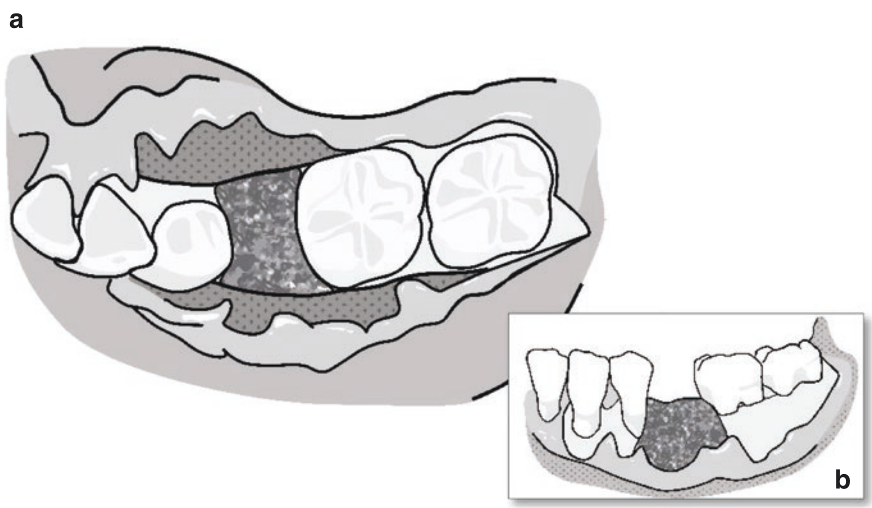


Fig. 33 (**a**, **b**) Placement of the graft (sticky bone) at the recipient bed

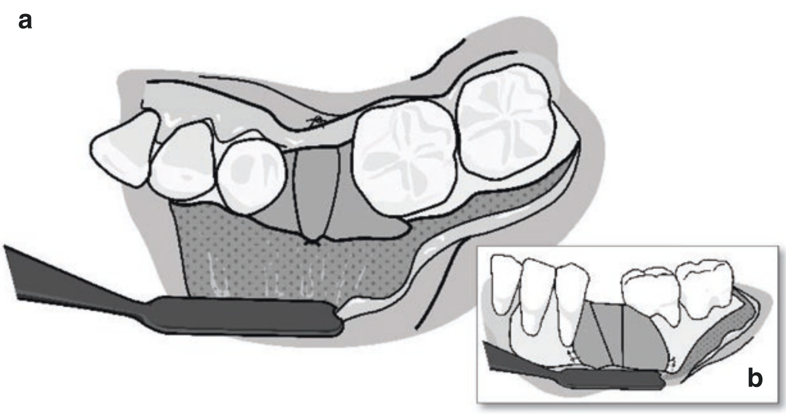


Fig. 34 (**a**, **b**) Membrane fixation with horizontal suspensory sutures, complementing the apical fixation with small-caliber microsurgical sutures (8-0, 9-0)

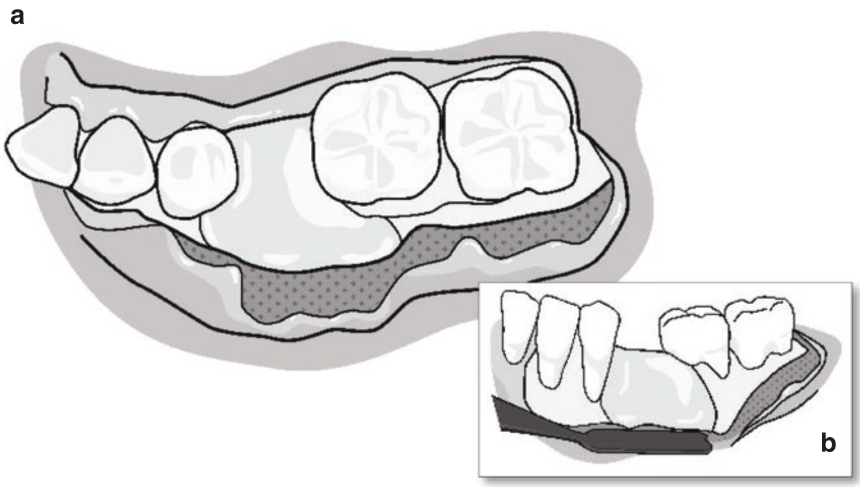


Fig. 35 (**a**, **b**) Placement of the L-PRF membrane over the regenerative materials before suturing of the microsurgical flap

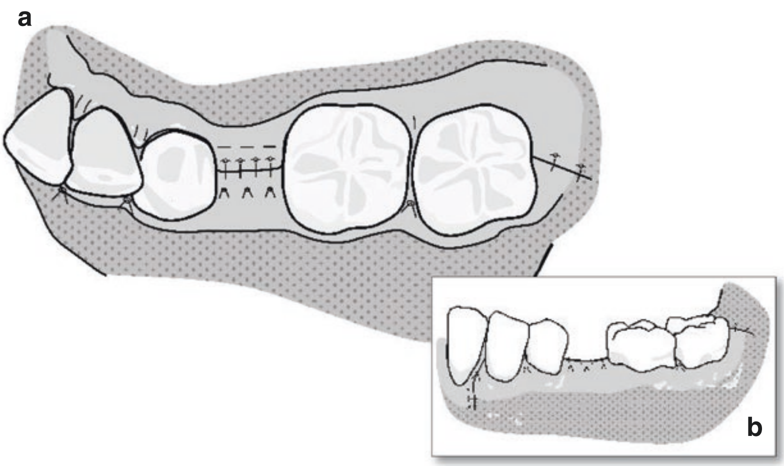


Fig. 36 (**a**, **b**) The main incision is closed with horizontal suspension mattress sutures, and interrupted sutures achieve optimal soft tissue closure. Interrupted microsurgical knots are placed along the vertical incisions

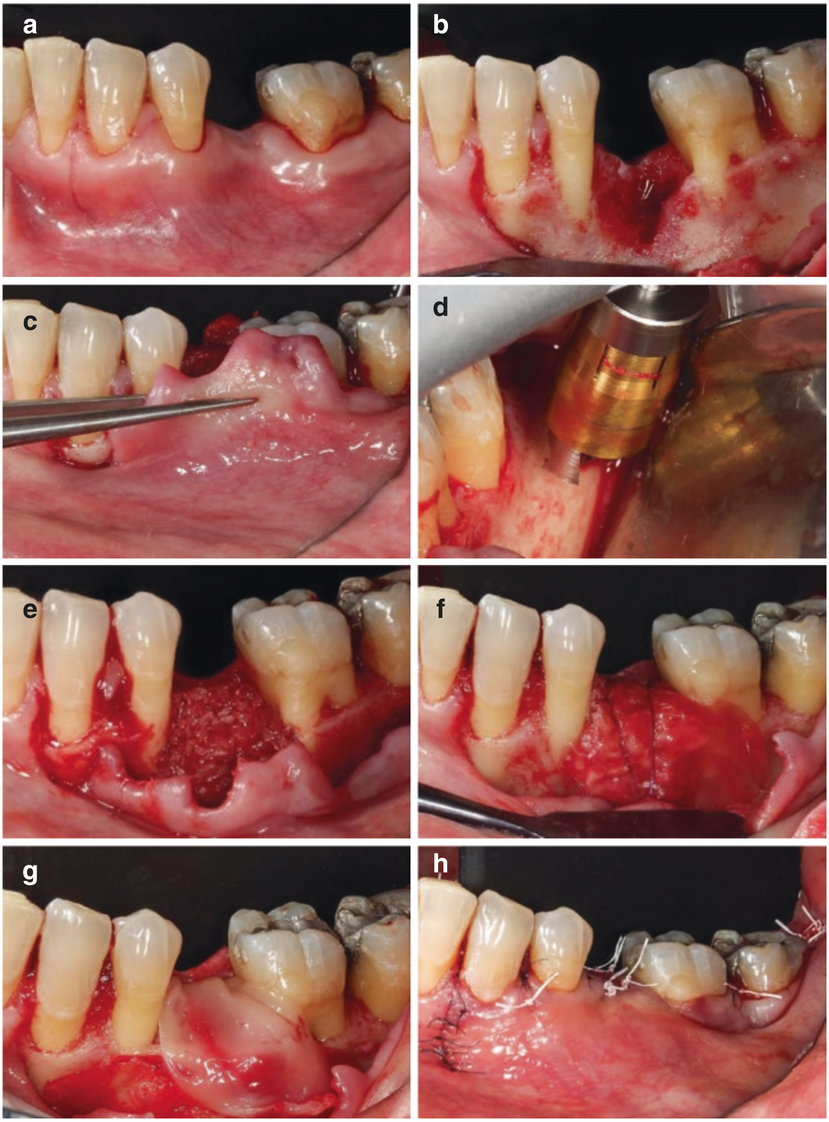


Fig. 37 Microsurgical guided bone regeneration images in a severe vertical-horizontal defect in the lower left second premolar region. (**a**) Primary incision and horizontal and vertical release incisions. (**b**) Microsurgical reflection. (**c**) The extension and release of the flap is verified by advancing it coronally. (**d**) Extraction of autologous bone from the mandibular branch. (**e**) Placement of the mixture of autologous bone and xenograft (Bio.Oss® bovine inorganic cancellous bone substitute) with autologous membrane L-PRF (sticky bone). (**f**) Placement of a long-lasting absorbable membrane (botiss Jasonz®). Membrane fixation with horizontal suspensory sutures using resorbable polyglycolic acid and caprolactone 5-0 sutures (RESORBA®, Glycolon™) complementing the apical fixation with small-caliber polyglycolic acid microsurgical sutures (8-0, 9-0). (**g**) Placement of an autologous membrane (L-PRF) on regenerative materials. (**h**) The main incision is closed with horizontal suspension mattress sutures, and interrupted sutures achieve optimal soft tissue closure. Interrupted microsurgical knots are placed along the vertical incisions

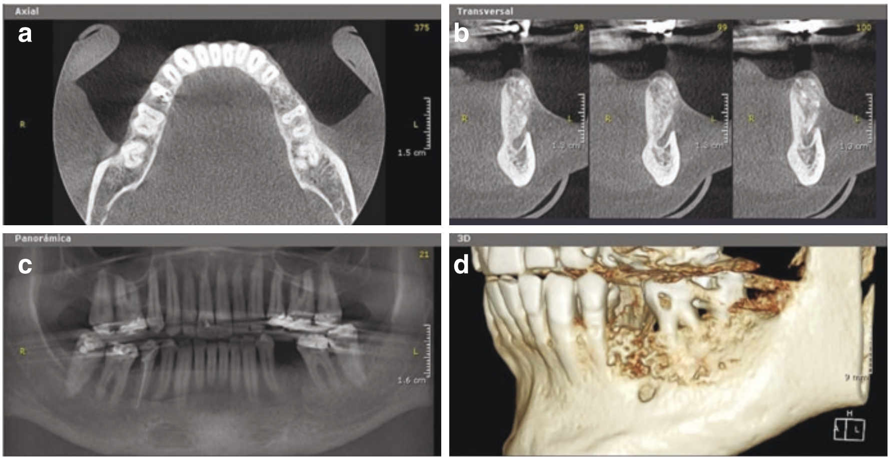


Fig. 38 (**a**–**d**) Axial, cross-sectional, panoramic, and cone beam 3D images showed healing 6 months after guided bone regeneration

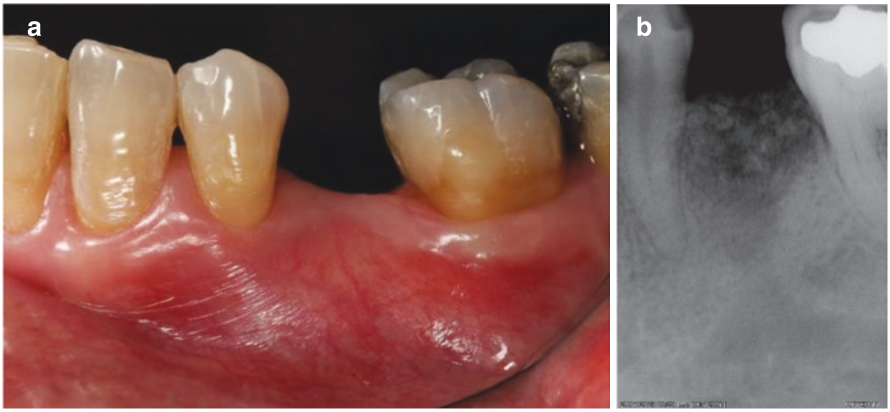


Fig. 39 (**a**) Six months following microsurgical regenerative therapy. (**b**) Progress of graft maturation seen on periapical radiograph

4.6 Membrane-Fixation Microsurgical Techniques

Performing the removal of granulation tissue and decortication under the microscope helps prepare the recipient site [66]**.** Visualization with a microscope also facilitates membrane adaptation, when it completely covers the defect, perhaps even 1–2 mm more and prevents contact with adjacent teeth, improving membrane fixation.

Non-resorbable membranes have complex handling characteristics, especially for fixation on the lingual or palatal site. The microsurgical access offered for condensed graft placement, with adaptation to the defect, is followed by efficient apical fixation of the membrane. The clarity provided by the microscope enhances the concentration and performance of the microsurgeon during this surgical step. There are different fixation kits for membranes, including tacks or mini-screws placed manually or with a low-speed power unit Fig. 40.

Resorbable membranes can be fixated with tacks, [53] but with resorbable suspensory horizontal sutures is usually adequate with Polyglycolic acid and caprolactone 5-0 (Glycolon™ Manufacturing: RESORBA® Nürnberg, Germany). Polyglycolic acid microsurgical sutures of a small caliber (8-0, 9-0) (Manufacturing USIOL®, Kentucky, USA) can contribute to the apical fixation of the membrane, with individual knots to the periosteum. The microsurgical technique enables suturing of an autologous membrane, L-PRF, to the periosteum on the apical and the lateral aspects of the surgical site with resorbable extra-fine sutures Videos 17, 18, 19 and Figs. 41a, b, 42, 43a, b, 44a, b.

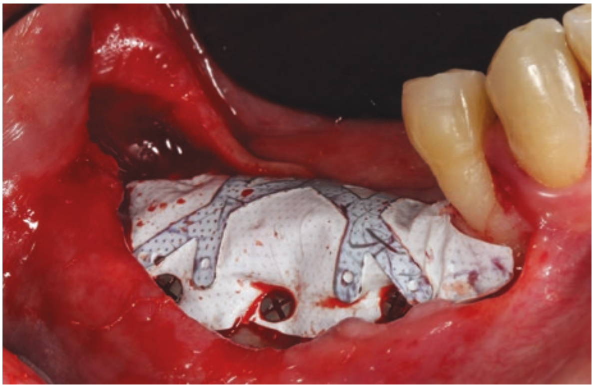


Fig. 40 Fixation of a non-resorbable PTFE™ membrane reinforced with titanium with screws from the Pro-fix™ fixation system

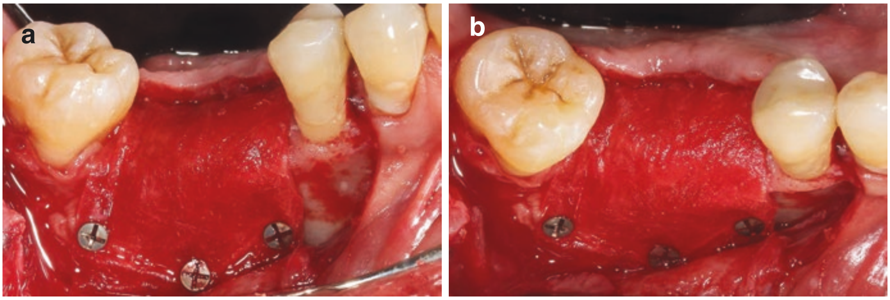
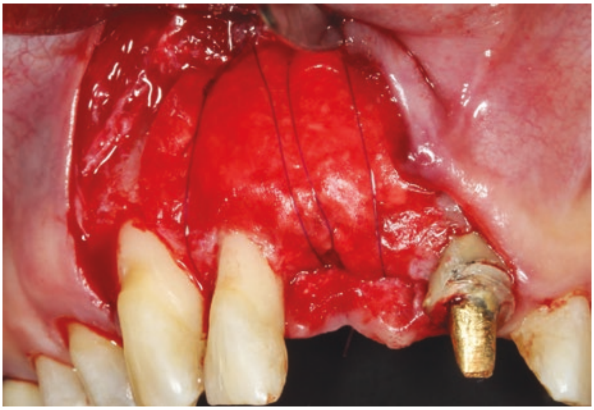


Fig. 41 (**a**, **b**) The buccal and occlusal images showed *Fixation* of absorbable membranes (BioMend Extend) with screws from the Pro-fix™ fixation system

Fig. 42 Resorbable membrane *fixation* (botiss Jasonz®) with suspensory sutures at the periosteum knotted on the palatal aspect of the flap



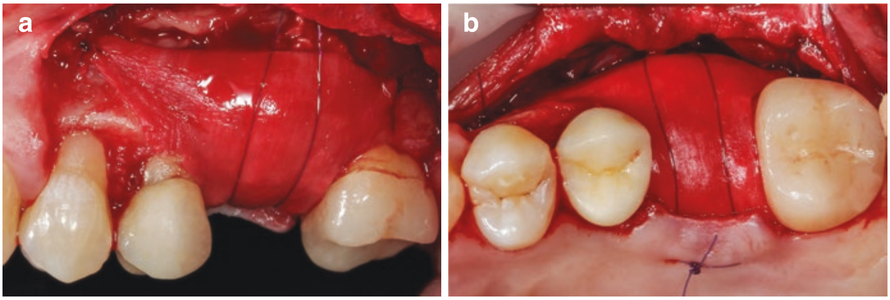


Fig. 43 (**a**, **b**). Buccal and occlusal views: resorbable membrane fixation (Geistlich Bio-Gide®) with suspensory suture to the periosteum complementing apical fixation with individual microsurgical knots

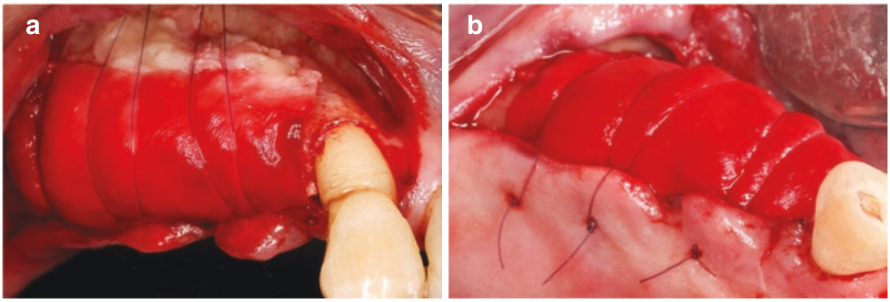


Fig. 44 (**a**, **b**) Buccal and palatal views: fixation of a resorbable membrane (Geistlich Bio-Gide®) with several vertical mattress sutures to the periosteum in a regenerative flap for vertical and horizontal augmentation in the posterior maxillary region

5 Microsurgical Sutures Specific to Bone Regeneration

A significant aspect of microsurgical GBR therapy is the primary closure of the wound; it is fundamental to preserving bone-graft integrity, thereby contributing to the success of the GBR procedure.

Suturing techniques in microsurgery require special instruments with unique handling characteristics. Active parts of these instruments help to place the microsurgical sutures and are approximately 18 cm long, with a design that provides support and comfort with controlled weight stability. The weight of any instrument should not exceed 20 g [17] to prevent muscle fatigue and allow balanced blocking forces while using the Castroviejo instruments.

These specifications assist the microsurgeon to effectively perform during flap closure. Also, the sutures of very small diameters are selected to reduce tissue trauma. The placement of sutures must be tension-free; when the tension exceeds during flap closure, the suture breaks [67]**.** Thus, the surgeon should use moderate force when tightening the knots to preserve the vascularity Figs. 45 and 46.

Fig. 45 The microsurgical instruments used in guided bone regeneration (Swiss Perio Kit for Hu-Friedy Selection Periodontal Microsurgery)

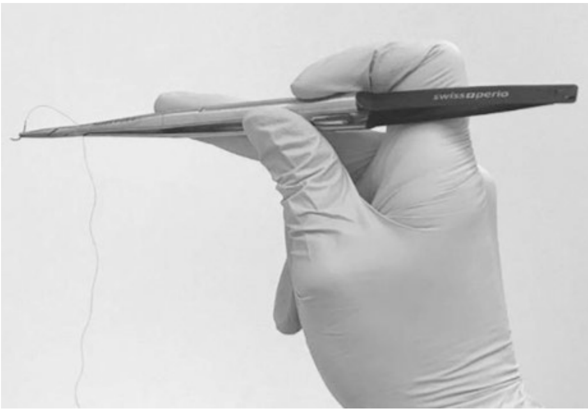


Fig. 46 The image shows a microsurgical needle holder with a correct grip, ensuring greater precision when suturing

5.1 Microsurgical Knots [68]

The microsurgical approach to placing knots includes some crucial factors: ergonomic position of the microsurgeon, use of instruments with sufficient handgrip, adequate forearm support to reduce physiological tremor [69], suture material selection, and adequate tension handling. These are fundamental requirements of microsurgery.

The technique involves handling of the instruments with bimanual skill, using the dominant hand to support the microsurgical Castroviejo needle holder, and handling the microsurgical forceps with the other one. The needle, preferably of a fine diameter, is handled through the suture. A variety of knots exist; the knot with the *nomenclature 2 = 2,* used with microsurgical techniques, consists of one double loop to the right and one double loop to the left, completed by tying the part with a space created between the sutures in the central part of the knot [70]**.**

This microsurgical knot (2 = 2) is placed across the vertical and horizontal incisions and with individual knots that complement suspensory sutures. These knots offer stability during wound healing, remaining intact during this period and providing resilience during the inflammatory processes related to healing. This microsurgical knot complies with the principles of periodontal microsurgery, and its advantages improve the effectiveness of GBR.

5.2 Suspensory Suture Technique

There is abundant scientific evidence to support the closure of the principal incision with suspensory horizontal mattress sutures in regenerative therapy. This suture is positioned on both the sides of the flap coronally, increasing the connective tissue contact on both sides and increasing the distance between the incision line and the membrane [44, 48, 50]**.** It is achieved by appropriately releasing the muscle fiber attachment to achieve passive displacement of the flap. Figure 47 presents the described technique. In addition to the required horizontal mattress, the regenerative flap receives a set of interrupted secondary sutures, microsurgical knots between

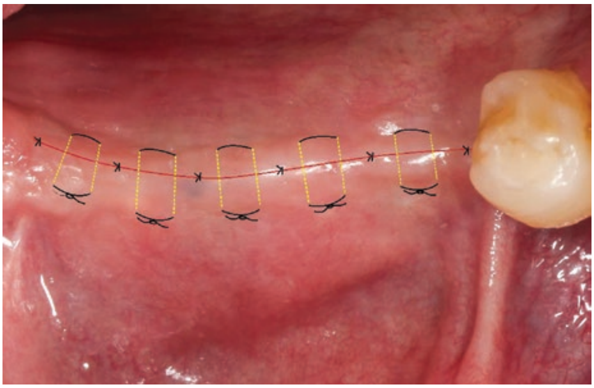


Fig. 47 Closure of the regenerative flap is performed with horizontal mattresses separated 3–4 mm from the incision, preferably within the keratinized tissue. Individual interrupted knots allow optimal soft tissue closure

every individual knot to complement closure over the incision line Videos 20, 21 and Figs. 48 and 49.

The crossed horizontal mattress sutures are very effective in alveolar preservation regenerative therapy, complementing the individual microsurgical knots for closure. Video 22 and Figs. 50, 51, 52 and 53.

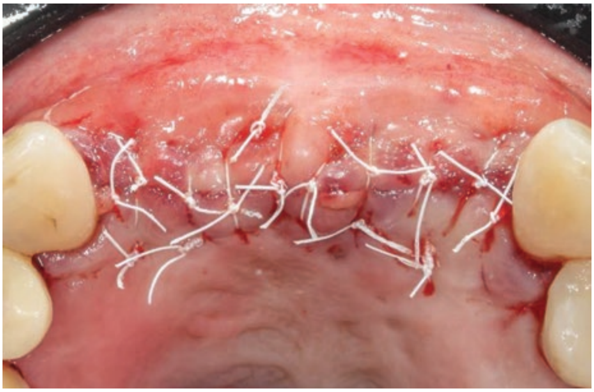


Fig. 48 The occlusal view shows the closure of the regenerative microsurgical flap with horizontal mattresses and interrupted individual knots

Fig. 49 Occlusal view of the tension-free flap closure using the double-layer suture technique, complemented with microsurgical sutures

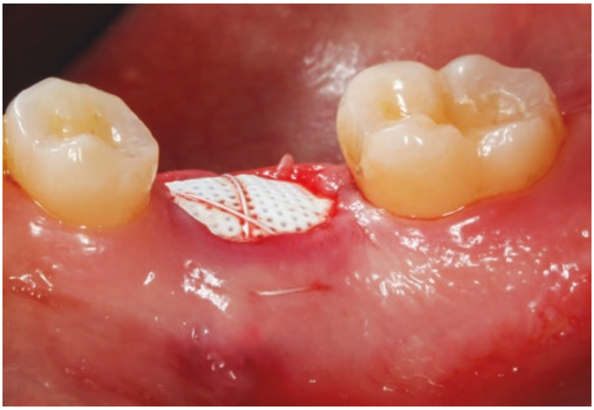


Fig. 50 Crossed horizontal mattress sutures for membrane *fixation* in microsurgical alveolar preservation therapy

Fig. 51 Occlusal images of bone preservation using microsurgical principles

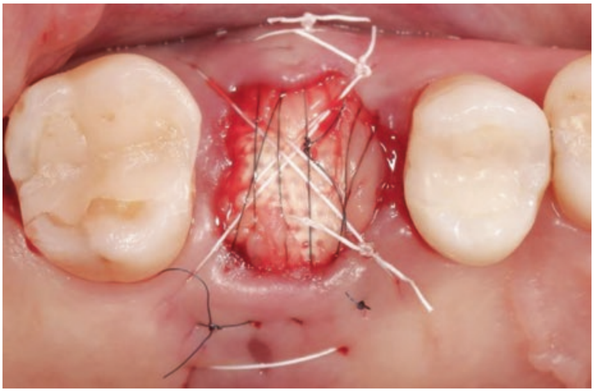


Fig. 52 Occlusal images of bone preservation using microsurgical principles

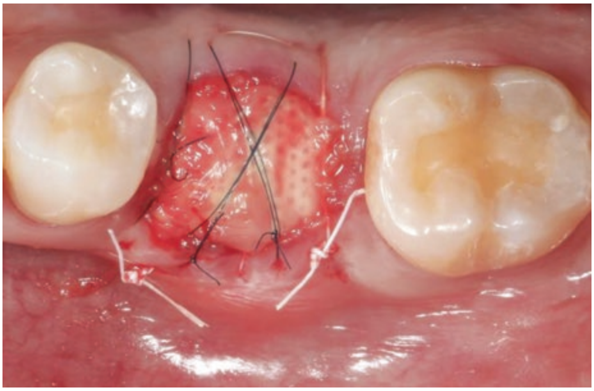


Fig. 53 Occlusal images of bone preservation using microsurgical principles

5.3 Different Suturing Materials

Knowledge of the biological aspects of different suturing materials, including their behavior and application, is part of preparation for microsurgery. The selected suturing material must be biocompatible, causing minimal tissue irritation and bacterial plaque accumulation. Suturing materials should have good quality and resistance, maintaining its strength until the wound has healed sufficiently to manage the tension with the help of the vascular changes in the healing tissue [22, 29, 67, 68].

The recommended suspensory suture for the primary incision (supra-ridge) is composed of PTFE (Cytoplast, manufactured by Osteogenics Biomedical, Inc., Texas, USA), which has all the required properties suitable for regenerative procedures, including strength and biocompatibility [44, 48, 50].

Surgeons can also use 6-0 nylon monofilament microsurgical sutures (Atramat®, manufactured by Obelis, Brussels, Belgium). For fragile tissues, 7-0 polyamide (Resolon™, manufactured by RESORBA® Nümberg, Germany) and 3/8 reverse needles are both recommended.

According to the case, a second suture composed of interrupted knots can be placed with PTFE (Cytoplast) or monofilament 6-0 nylon (Atramat®). The microsurgical intermediate knots are placed using non-resorbable 7-0 polyamide (Resolon™). In the fragile tissues or critical areas, sutures are placed with even smaller needles than those described earlier, with 10-0 nylon threads (Atramat®).

A flap raised at an implant site for procedures aimed at gaining keratinized tissue and vestibular repositioning should be sutured with 7-0 polyamide (Resolon™), 8-0, 9-0 polyglycolic acid (USIOL®), or 5-0 glycolic acid copolymer and caprolactone (Glycolon™) sutures.

6 Post Microsurgical Management

Patient selection is essential and requires medical evaluation to determine health and adequate control of systemic diseases and oral hygiene. Smokers are required to quit smoking 1–2 weeks before the surgery and during the healing process (for a minimum of 3 weeks, and ideally for 6 weeks). Patients with a compromised medical status or a history of extensive surgeries under sedation are required to undergo hematic biometry, biochemical profile, and coagulation tests before surgery.

6.1 Postoperative Indications

Patients require a liquid diet for the first 72 h postoperatively, and sometimes for longer for patients who have undergone prolonged or complex surgery procedures.

A diet of soft foods should be administered for the following 10 days. The diet evolves according to the healing process.

During the first hours, patients are instructed to take bed rest and avoid facial muscle movement. Pausing activities that stimulate blood flow is essential, as is applying a cold dressing to the affected area 48–72 h after the surgery. Suspension of dental hygiene in the surgical and adjacent areas and the use of antiseptics are essential. Patients should use an antiseptic mouthwash with a neutral pH and an active substance including chlorine and oxygen (0.0015%) to contain the microbial spectrum. Also, rinsing with chlorhexidine gel or solution is prescribed for at least the first 15–21 days [71–73]**.** The surgeon usually prescribes amoxicillin with clavulanic acid (875/125 mg) once every 12 h for 7–10 days. In case of allergy to penicillin drugs, clindamycin is the next choice. Anti-inflammatory medication, such as potassium diclofenac, 50 ml every 12 h, starting the night before the microsurgery, is also prescribed. For prolonged surgeries, intravenous sedation with intake of steroid anti-inflammatories is recommended, and in cases of intra-operative pain, sublingual administration of 30 mg ketorolac is done.

6.2 Microsurgical Suture Removal

A microsurgical suture eliminates vertical incisions. Microsurgical knots across the main incision are evaluated using microscope magnification and removed on the fifth day under higher magnification, carefully cleaning the sutures before being cut to avoid introducing bacteria in the tissue. The suspensory sutures are removed between postoperative days 10 and 21 Video 23.

7 Microsurgical Management of Postoperative Complications

The risk of complications after microsurgery can be reduced by carefully following each step of the technique being performed. The use of microscopes helps achieve this, along with gentle handling of tissues, precision, realizing incisions, and protection of the periosteum. The suture must be placed tension-free, and materials that induce minimal tissue reaction are selected.

Membrane exposure is one of the most frequent complications affecting the outcomes of GBR procedures. In such a situation, the proliferation of pathogens can occur at the site of the failed regeneration [74]**.** Therefore, the surgeon should treat the incident immediately, following established protocols depending on the degree of exposure. Non-resorbable membrane exposures are more common and are classified according to the healing complications: Class I (<3 mm) and Class II (>3 mm), both without the presence of purulent exudate, can be treated locally with the application of chlorhexidine gel (0.12%) over the area 2–3 times a day [75]. Classes III and IV are advanced cases with infection; they require membrane elimination with antibiotic therapy. For the management of this complication, the author proposes the placement of an autologous L-PRF membrane over the exposed area and stabilizing it at the tissue surrounding the perforation by placing 8-0, 9-0 polyglycolic acid sutures (USIOL®). The results are usually observable within hours. For extensive exposures or development of infection, the surgeon must eliminate the contaminated membrane and place a native collagen resorbable membrane, placed over an autologous L-PRF membrane sutured as described above, with prescription of antibiotics and chlorhexidine gel for infection control Video 24.

8 Soft Tissue Management and Vestibular Repositioning After Bone Regeneration

Under ideal conditions, GBR provides the amount of bone necessary to comply with the clinical parameters of success. Peri-implant tissue health maintenance with low inflammation levels and stable marginal bone levels determine long-term graft integrity [76, 77]. Recent evidence describes total periodontium reconstruction, including that of soft tissue, in which combined augmentation of bone and soft tissue results in a positive inter-implant gingival contour [78]. Most analyses associate an increase in dental bacterial plaque accumulation with soft tissue inflammation, gingival recession, and marginal bone loss around implants when less than 2 mm of keratinized tissue is present [79–82]. However, controversy still exists regarding the role of soft tissue behavior, thickness, and height; keratinized tissue width; and their relation to these treatments. The treatment-related decisions are dependent on the surgeon's discretion. There is a specific clinical situation in which soft tissue augmentation with periodontal plastic surgery may be justified [83, 84]. The use of a surgical microscope has been described in periodontal plastic treatment before [17, 28]. This discipline is related to microsurgery as it requires technical finesse. We observe the benefits of this technology in soft tissue management using magnification. Evidence demonstrates that magnification increases the coordination between the surgeon's hand and arm motor muscles and improves cognitive abilities with training. These benefits increase on using microsurgical instruments and suturing materials designed to decrease trauma during tissue handling. In periodontal microsurgery, minimally invasive incisions reduce trauma, and using appropriate wound closure techniques prevents cellular necrosis, resulting in faster wound-healing as compared with macrosurgical procedures [22, 28].

8.1 Vestibular Deepening

The large displacement of the flap to achieve closure may result in vestibular loss and mucogingival alterations. Vestibular repositioning has a high degree of success when performed with simultaneous free gingival graft placement, which would result in a gain in keratinized tissue. The last step of GBR treatment precedes placement of the definite prosthesis, performed in the secondary stage or simultaneously with implantation if the technique allows it. Figures 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65a, b, 66a–c, 67a–j.

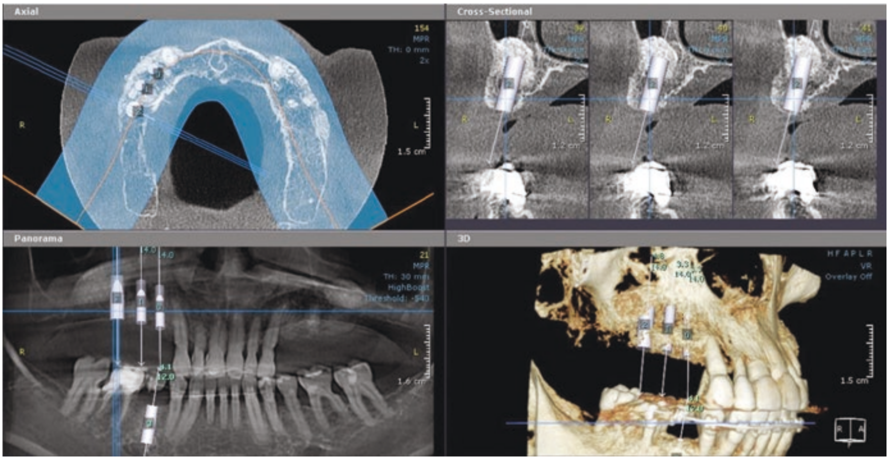


Fig. 54 Axial, cross-sectional, panoramic and cone beam 3D images demonstrating the results of guided bone regeneration, with maxillary sinus lift and planning for implant placement

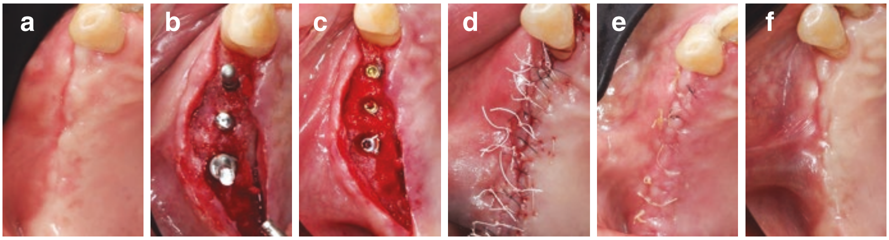


Fig. 55 (**a–f**) Occlusal images of implant placement surgery 9 months after microsurgical guided bone regeneration in the right posterior maxilla, showing a loss of vestibule with significant mucogingival distortion created by the surgical procedure

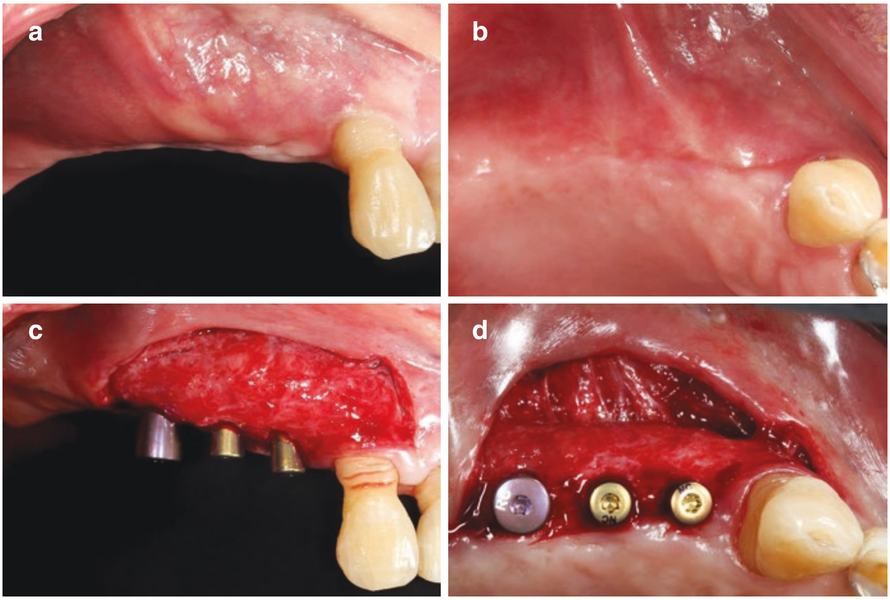


Fig. 56 (**a**–**d**) Soft tissue management and vestibular repositioning after bone regeneration. (**a**, **b**) Buccal and occlusal views show distortion of the mucogingival line after regenerative procedures and implant placement. (**c**, **d**) Buccal and occlusal views of microsurgical preparation of the surgical bed with a partial-thickness flap displacing the vestibule apically, with initiation of the incision on the occlusal aspect. Healing abutments were placed during second stage surgery

Fig. 57 Free gingival graft of an adequate thickness (less than 2 mm) obtained under magnification and trimmed for adaptation to the healing abutments

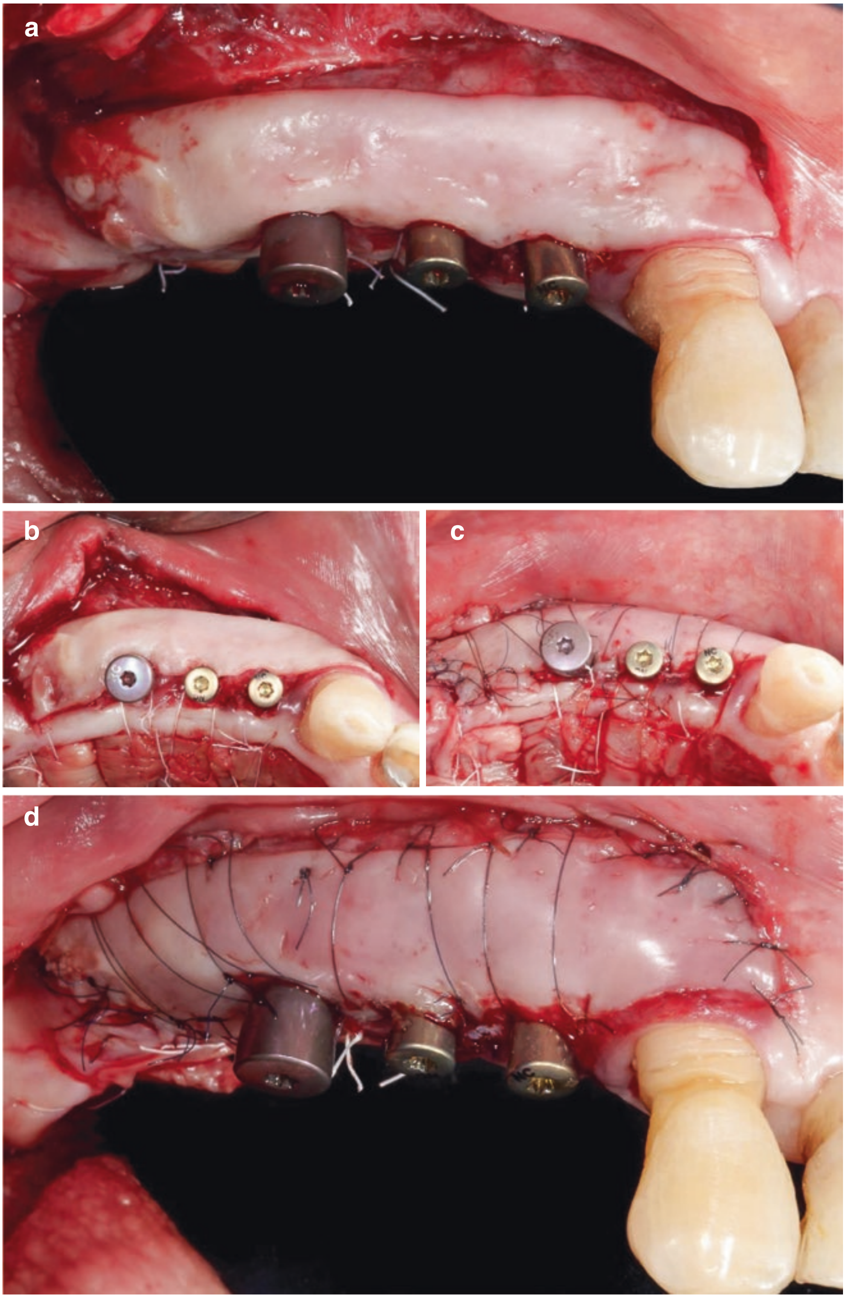


Fig. 58 (**a**, **b**). Buccal and occlusal images of free gingival graft placement, corroborating the extension and adaptation in the recipient site. (**c**, **d**). Buccal and occlusal view of graft stabilization with microsurgical suturing techniques using small-caliber polyamide 7-0 (Resolon™) and glycolic acid copolymer 5-0 and caprolactone (Glycolon™) sutures to the periosteum with apical displacement the vestibule

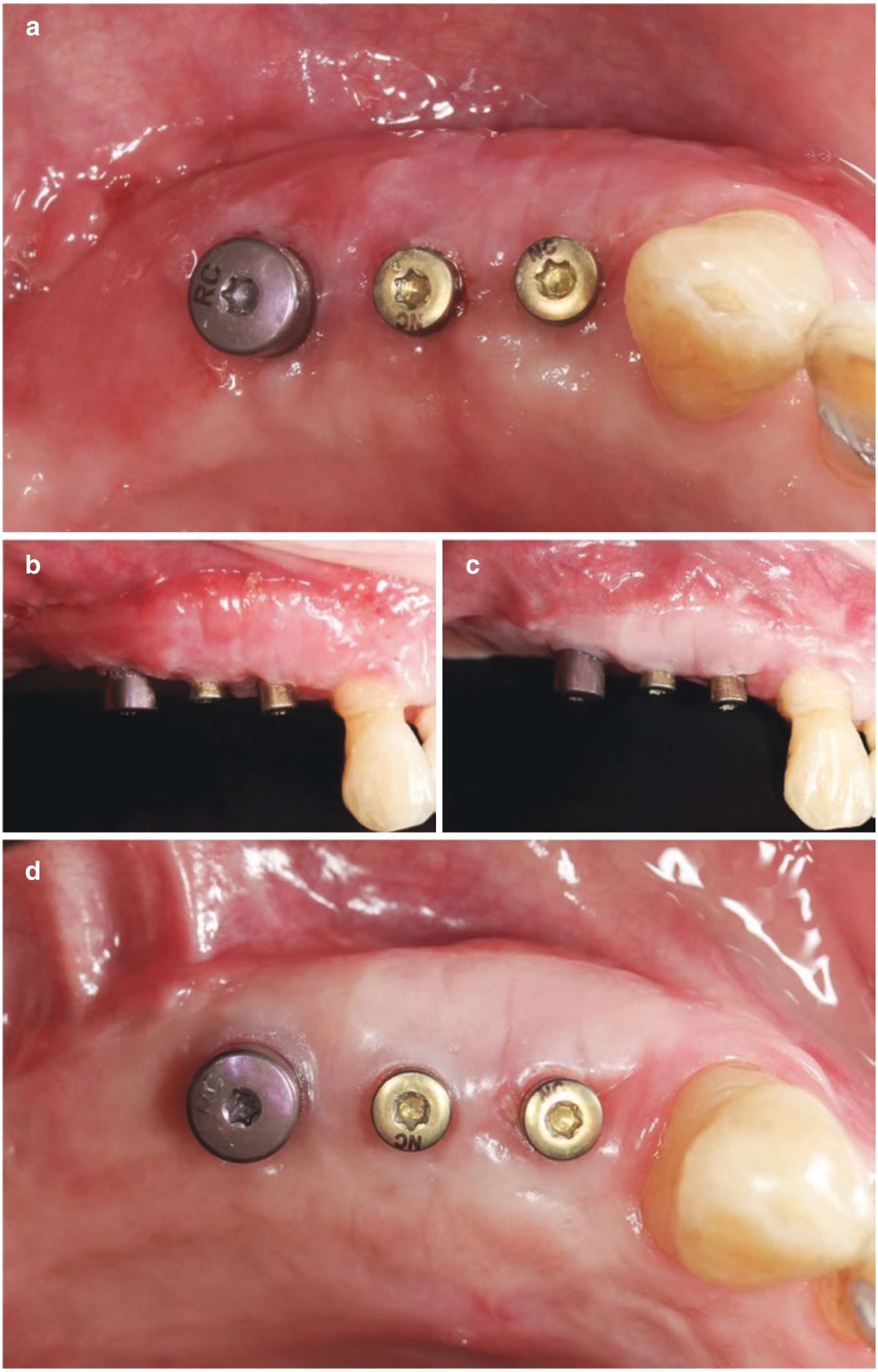


Fig. 59 (**a**, **b**). Buccal and occlusal images of the grafted site 3 weeks after graft placement. (**c**, **d**). Buccal and occlusal images show uniform integration of the graft 6 weeks postoperatively

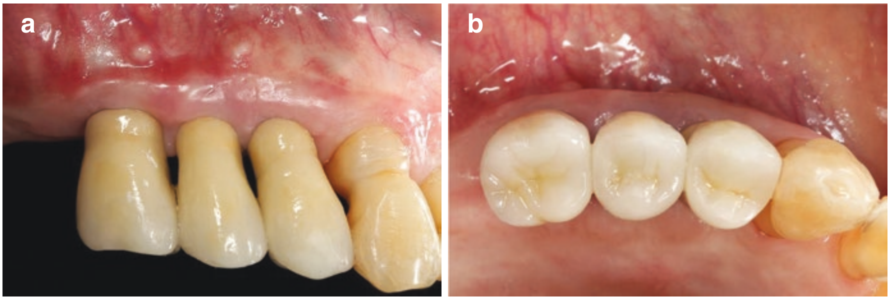


Fig. 60 (**a**, **b**) Buccal and occlusal views of the final restoration, vestibular repositioning, and soft tissue modification with increased keratinized tissue

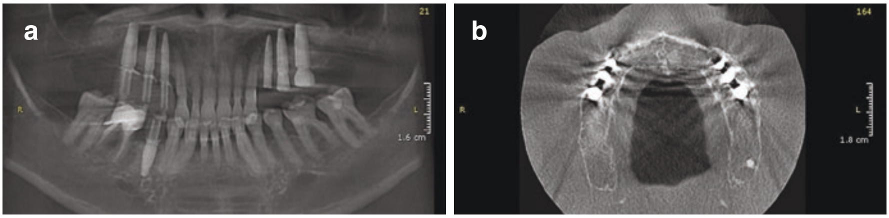


Fig. 61 (**a**, **b**) Panoramic and axial cone beam images showing the results of guided bone regeneration in posterior maxillary areas and planning for implant placement

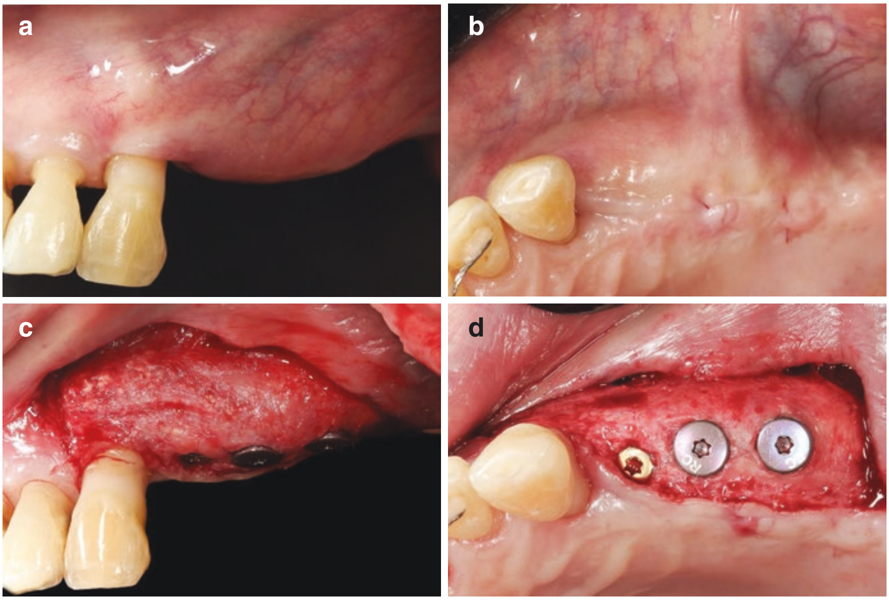


Fig. 62 (**a**, **b**). Buccal and occlusal views show distortion of the mucogingival line after regenerative procedures and implant placement in the left posterior maxilla. (**c**, **d**) Buccal and occlusal views of the microsurgical preparation of the surgical bed with a partial-thickness flap displacing the vestibule apically after initiating the incision in the occlusal aspect, performing the second stage by placing the healing abutments

Fig. 63 The free gingival graft is taken under high magnification. The size of the graft depends on the horizontal and vertical extension of the recipient bed

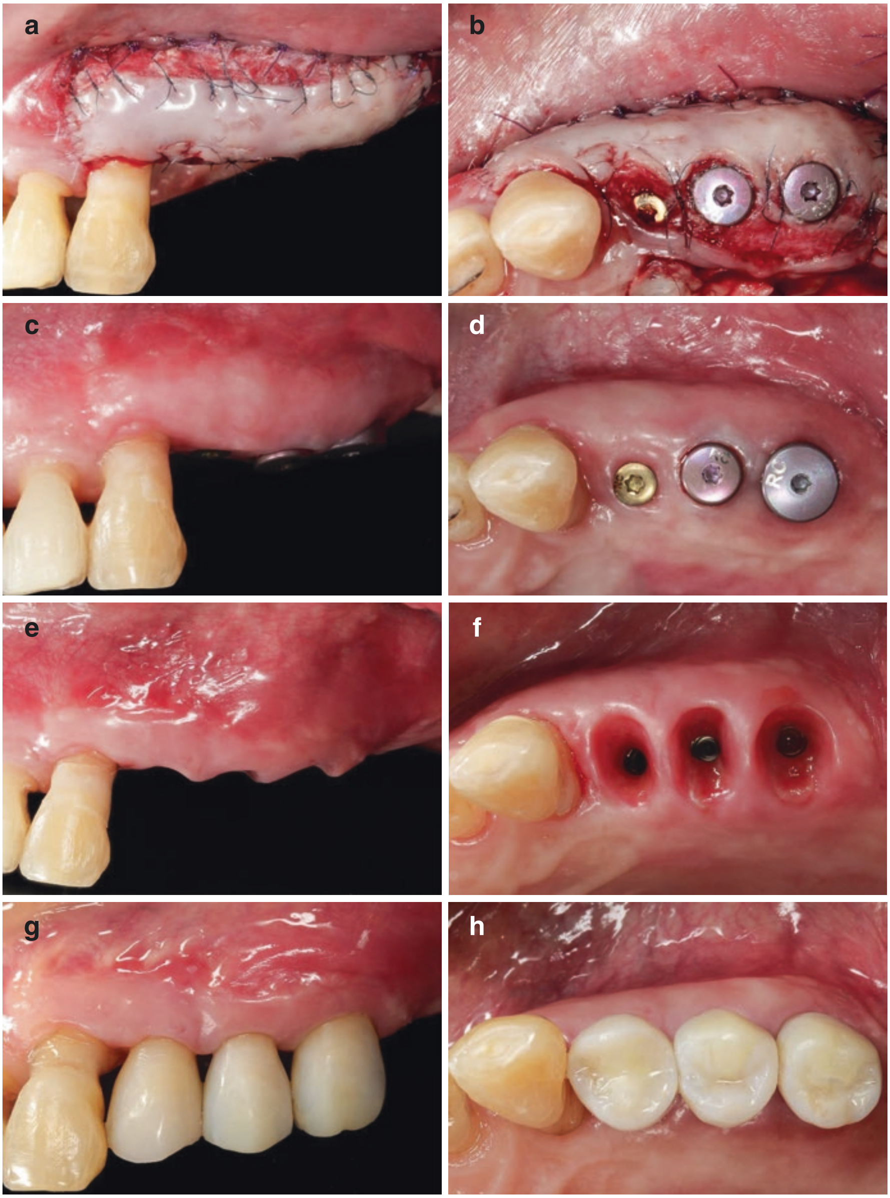


Fig. 64 (**a**, **b**) Buccal and occlusal images of the free gingival graft fixed with microsurgical suture techniques. Using 7-0 polyamide (Resolon™) at the occlusal, apical, and distal ends, 8-0 polyglycolic acid, 9-0 mesially (USIOL®), and glycolic acid and caprolactone copolymer (Glycolon®) apical to the periosteum 5-0™. (**c**, **d**). Buccal and occlusal view of the graft at six weeks of healing. (**e**–**h**) Buccal and occlusal view of the healed free gingival graft with a significant gain in keratinized tissue. Observe the formation of the emergence profiles 4 months after of using provisional restorations

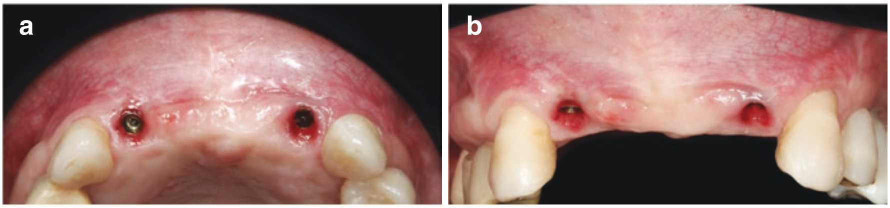


Fig. 65 (**a**, **b**) Buccal and occlusal views of a significant mucogingival distortion following guided bone regeneration in the anterior maxilla

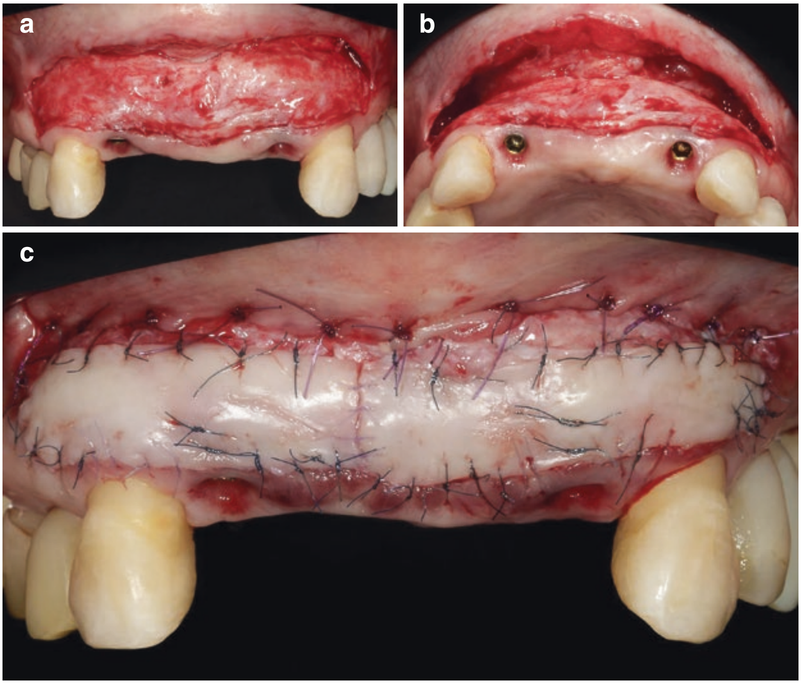


Fig. 66 (**a**, **b**) Buccal and occlusal views of the microsurgical partial-thickness flap bed preparation using an operating microscope. The releasing muscle attachments carefully result in a non-moving receptor bed. (**c**) The image shows a free gingival graft taken from the palate in two sections and sutured to each other with microsurgical sutures (8-0). The graft is then sutured to the recipient bed with individual microsurgical knots using 7-0 polyamide monofilament sutures (Resolon™) at the ends, 8-0, 9-0 polyglycolic acid sutures (USIOL®) and glycolic acid copolymer 5-0 and caprolactone (Glycolon™) sutures to the periosteum with apical displacement the vestibule

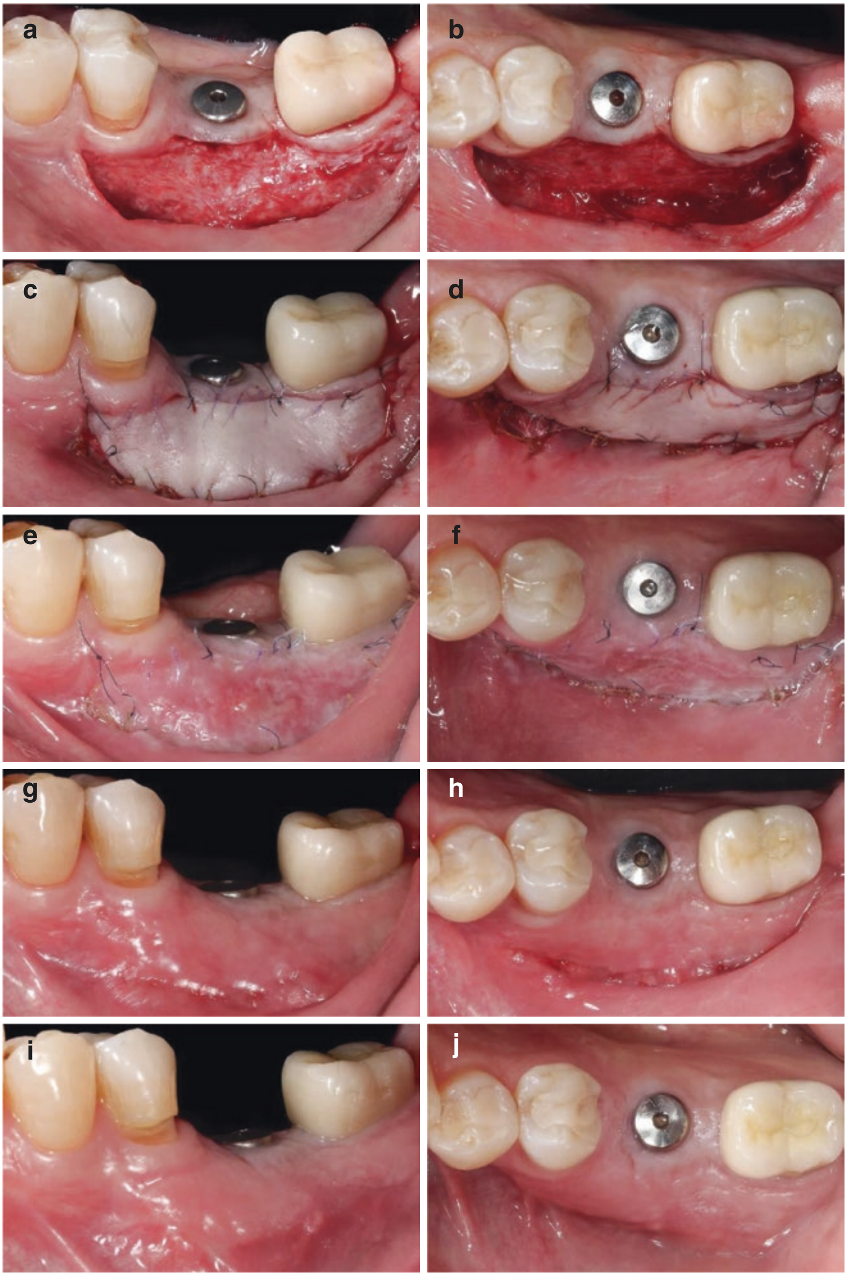


Fig. 67 (**a–j**) Soft tissue management and vestibular repositioning after bone regeneration in the lower left first molar (3.6). (**a**, **b**) Preparation of the bed respecting the margin of keratinized tissue. (**c**, **d**) Free gingiva graft fixation and adaptation with individual microsurgical knots using 7-0 polyamide monofilament suture (Resolon™) at the ends with 9-0 polyglycolic acid sutures (USIOL®). (**e**, **f**) Healing 12 days postoperatively. (**g**, **h**) Healing 26 days postoperatively. (**i**, **j**) Healing 40 days postoperatively. Note the significant gain in keratinized tissue and soft tissue integration

The integration of periodontal plastic surgery principles increases or modifies soft tissue, contributing to the functional and esthetic improvement in regenerative therapy. Trained surgeons utilize different techniques to perform this task, and there are many graft materials, such as free gingival grafts, connective tissue grafts, allografts, and xenografts that may be used. The selection of the technique and graft would depend on the chief objective and the available corresponding scientific evidence [85–87] (Figs. 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78).

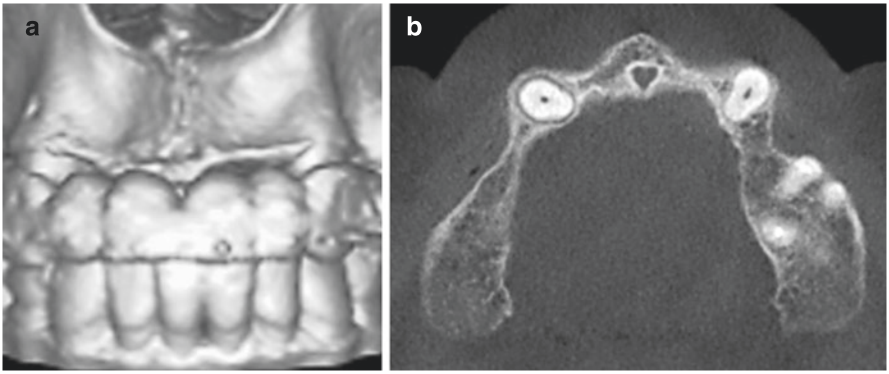


Fig. 68 (**a**, **b**) 3D and axial cone beam images of severe deficiency in the bucco-palatine direction in the anterior maxillary region

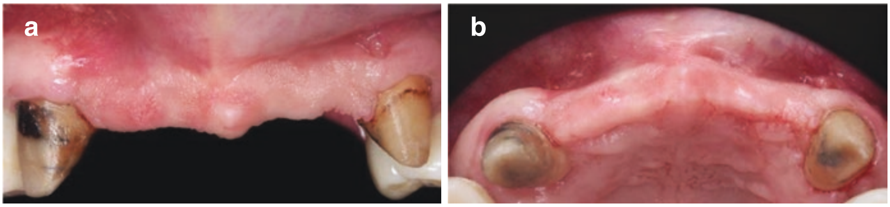


Fig. 69 (**a**, **b**) Buccal and occlusal images of horizontal ridge deficiency with integrity of the apico-coronal dimensions

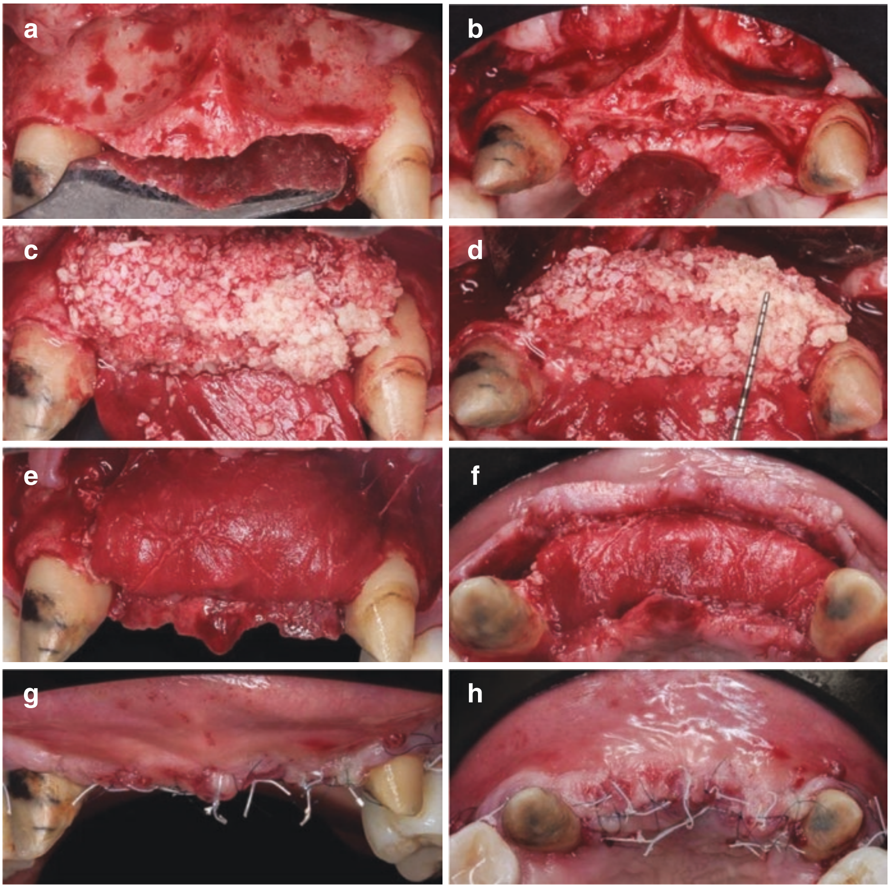


Fig. 70 (**a**–**h**). Representative case of horizontal augmentation in the anterior maxilla utilizing a microsurgical approach. (**a**, **b**) Buccal and occlusal view of a thin anterior superior ridge. (**c**, **d**) Buccal and occlusal view of the bone graft. (xenograft particulate anorganic bovine bone Bio.Oss® combined with cancellous bone allograft Puros®). (**e**, **f**) Placement and fixation of the membrane on the graft. (**g**, **h**) The flap is sutured with horizontal double mattresses complementing individual microsurgical knots

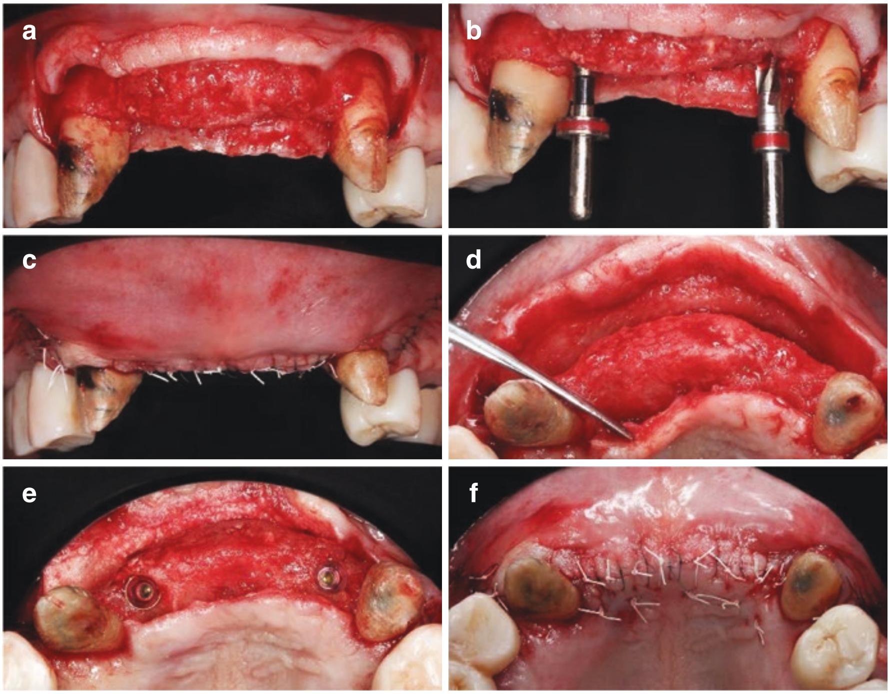


Fig. 71 (**a**, **d**) Buccal and occlusal views of the microsurgical flap showing the regenerated bone after 9 months of healing. (**b**, **e**) Buccal and occlusal views of implants placed in the regenerated bone. (**c**, **f**) Images of double-layered closure with individual microsurgical knots

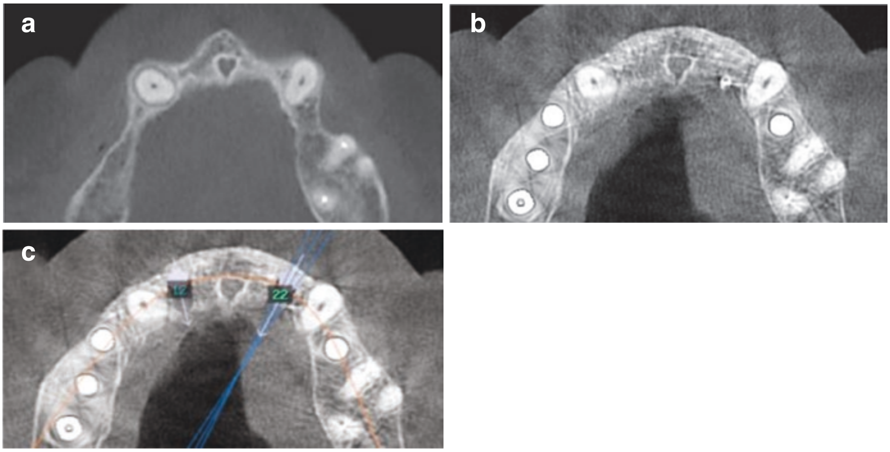


Fig. 72 (**a**) Axial image showing severe maxillary atrophy. (**b**, **c**) Images showing the results of guided bone regeneration and planning for implant placement

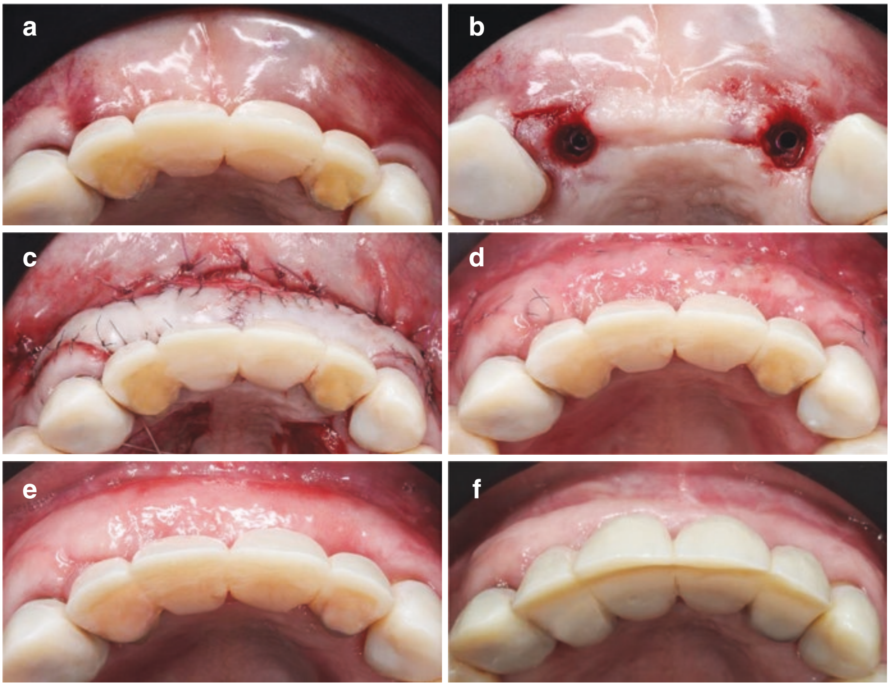


Fig. 73 (**a**, **b**) Occlusal image of significant mucogingival distortion created by guided bone regeneration in the anterior maxilla. (**c**) Vestibular deepening with simultaneous placement of a free gingival graft with a microsurgical approach. (**d**, **e**, **f**) Postoperative healing of the free gingival graft at 3 weeks, 2 months, and 1 year, respectively

Fig. 74 Buccal view 1 year after free gingival grafting and vestibular deepening

Fig. 75 (**a**, **b**, **c**) Buccal, occlusal, and lateral views showing the quality and maturation of the keratinized tissue after 1 year and 4 months of using provisional restorations and healing of the free gingival graft. (**d**, **f**) Lateral and vestibular view of the definitive restoration 2 years after microsurgical bone regeneration. (**e**) Implant-supported restoration

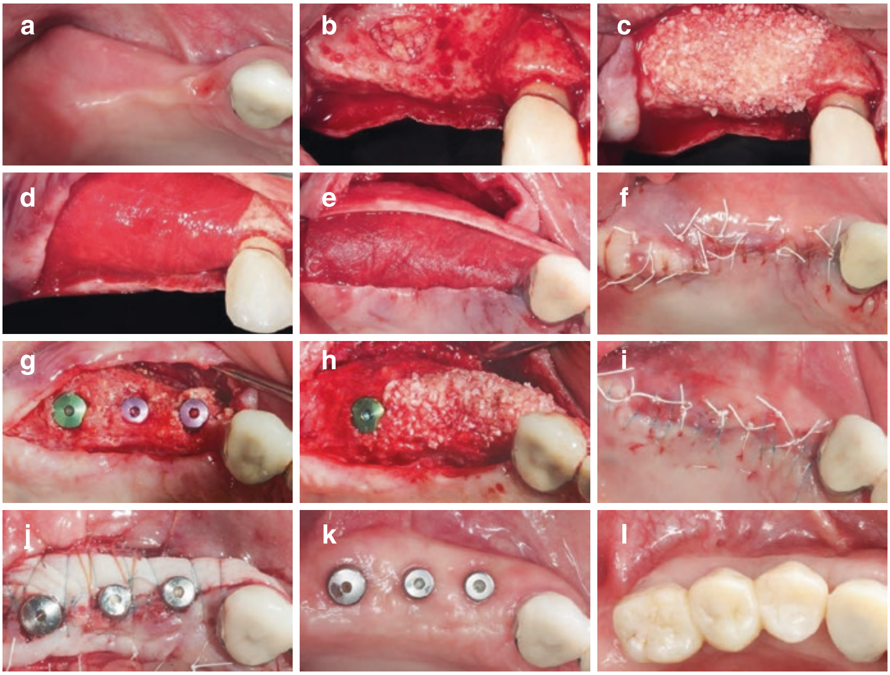


Fig. 76 Alveolar ridge augmentation with maxillary sinus elevation using a microsurgical approach. (**a**) The initial occlusal view shows a significant horizontal defect. (**b**) Buccal view of the defect area with elevated maxillary sinus shows the preparation of the recipient bone bed with multiple decorticalization holes. (**c**) Surgical image showing the placement of mixed xenograft (Bio.Oss® bovine inorganic cancellous bone substitute) and cancellous bone allograft (Puros®) and its adaption to the bone defect before membrane placement. (**d**) Buccal view of the membrane in place. (**e**) Occlusal images show a resorbable membrane (Geistlich Bio-Gide®) complemented with an acellular dermal matrix (AlloDerm™). (**f**) Closure of the flap at the primary incisions with horizontal mattress suture and individual interrupted knots. (**g**, **h**). Occlusal view of the implants in place and placement of bone substitute. (**i**) Occlusal view of tension-free flap closure. (**j**) Occlusal view of a free gingival graft placed around the implants. (**k**) Two months postoperatively. Note the significant gain in keratinized tissue and soft tissue integration. (**l**) Occlusal view of the temporary restorations placed and healing 1 year after free gingival grafting

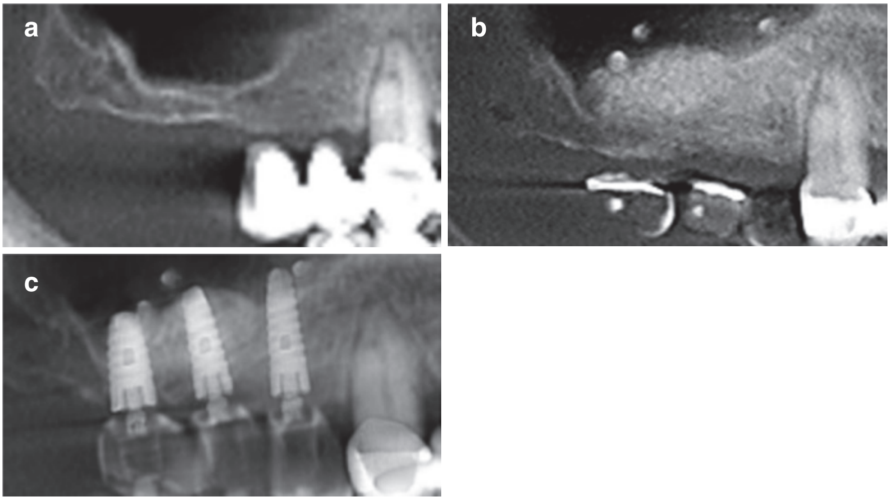


Fig. 77 (**a**) Preoperative radiograph. (**b**) Radiograph taken following guided bone regeneration and sinus lift. (**c**) Radiograph taken 1 year after implant loading

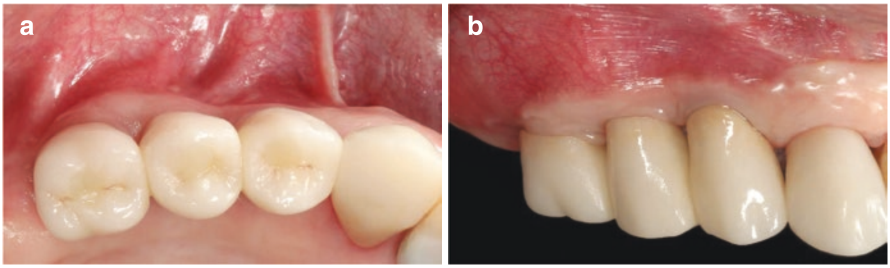


Fig. 78 (**a**, **b**). Occlusal and buccal views of the definitive restoration 2 years after microsurgical bone regeneration

8.2 Connective Tissue Grafts for Increased Thickness

Procedures using autogenous connective tissue grafts increase thickness and induce keratinization at sites indicated for or those that have undergone augmentation procedures. These procedures can precede regenerative surgery in areas with an extremely thin periodontal biotype to improve its management during regenerative microsurgery. It is also possible to perform it simultaneously or compensation treatment parallel to the prosthetic therapy with subgingival prothesis profiles, creating ideal gingival anatomy. References [88–90] show the application of microsurgical principles in connective tissue graft techniques Video 25 and Figs. 79, 80, 81, 82, 83, 84, 85, 86, 87a–g.

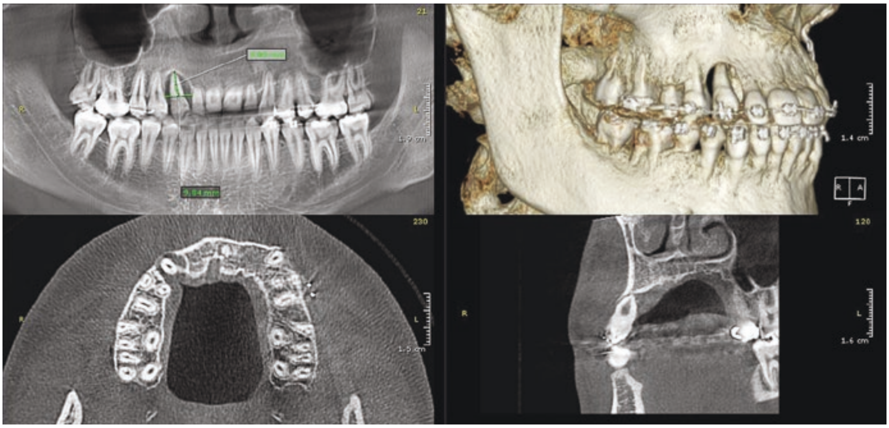


Fig. 79 Panoramic, axial, transverse, and cone beam 3D images, showing a severe vertical and horizontal defect in the area of the right upper canine

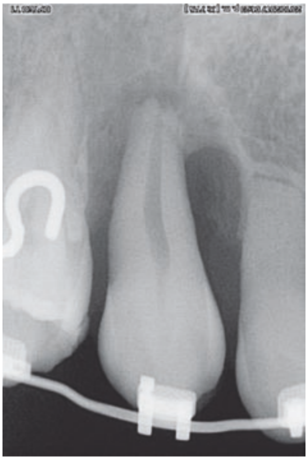


Fig. 80 Periapical radiograph showing apical extension of the severe circumferential bone defect at the right upper canine

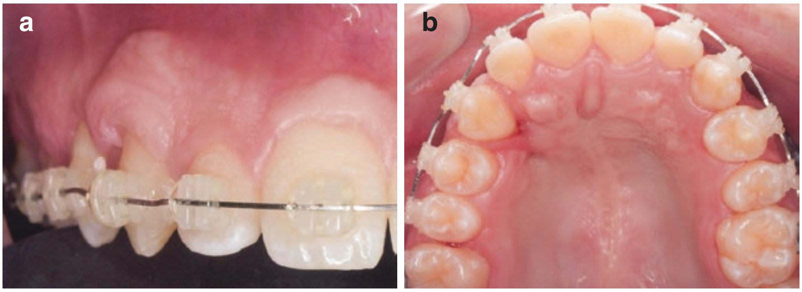


Fig. 81 (**a**, **b**). Buccal and occlusal clinical images taken preoperatively

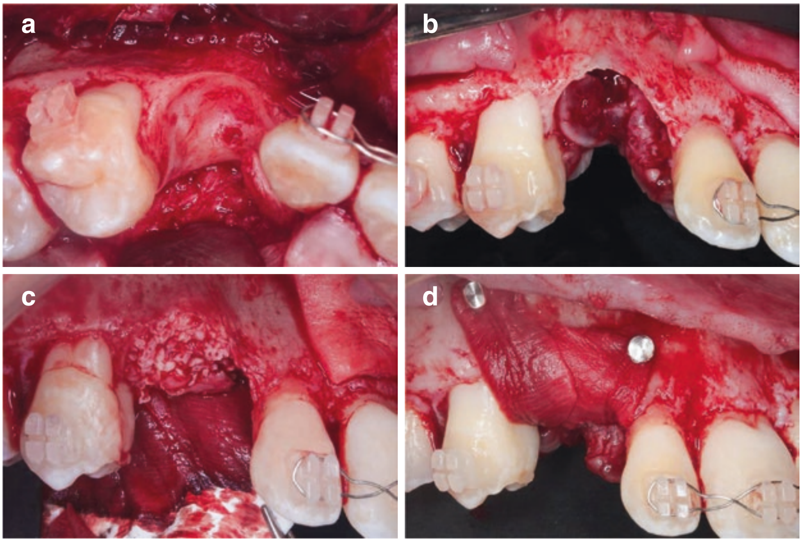


Fig. 82 (**a**, **b**). Occlusal and buccal images of the full thickness microsurgical flap after canine extraction showing loss of palatal alveolar bone as well as a pronounced vertical deficiency. (**c**) Placement of the mixture of autologous bone and xenograft (Bio.Oss® bovine inorganic cancellous bone substitute). (**d**) Buccal images show a resorbable membrane (Geistlich Bio-Gide®) immobilized with titanium pins

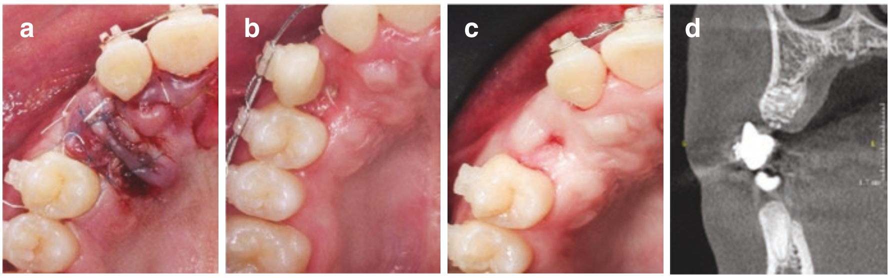


Fig. 83 (**a**) The flap is sutured with horizontal double mattresses complemented with individual microsurgical knots. (**b**, **c**) Healing at 3 and 6 weeks after guided bone regeneration. (**d**) The cross-sectional image showed progress in healing 7 months after guided bone regeneration and bone preservation

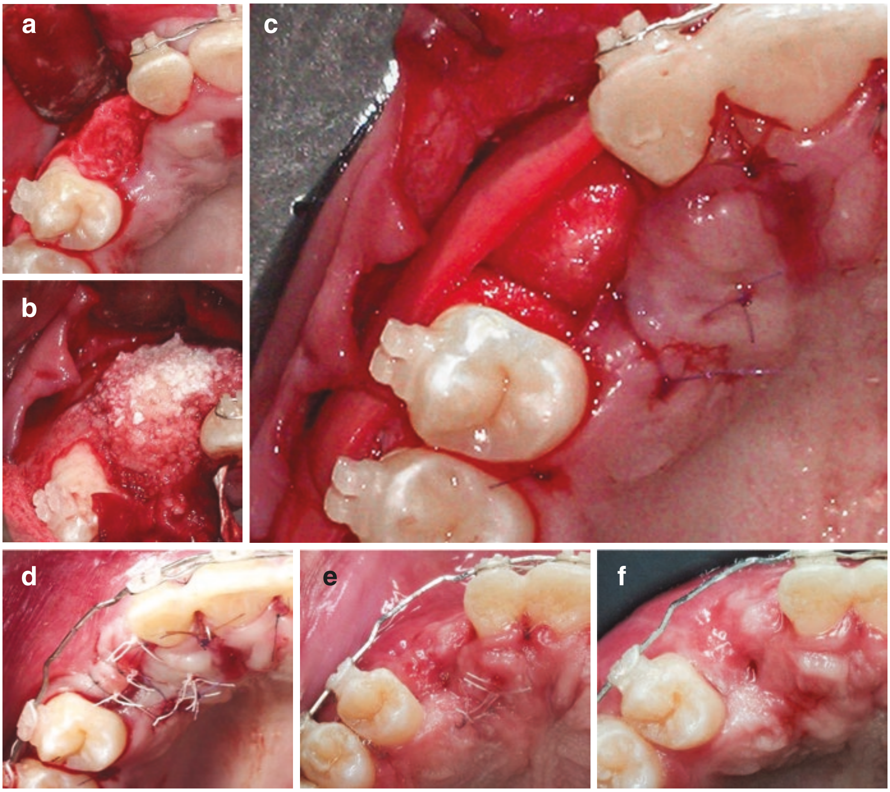


Fig. 84 (**a**) Occlusal image of the full-thickness flap showing the results of the first guided bone regeneration microsurgical procedure. (**b**) Bone graft placement with a mixture of xenograft (Bio. Oss® Bovine Inorganic Cancellous Bone Substitute) and cancellous bone allograft (Puros®). (**c**) Occlusal view shows resorbable membrane fixation (Geistlich Bio-Gide®) performed with suspension sutures for the periosteum and dermal matrix (AlloDerm®) for soft tissue augmentation. (**d**) The flap is sutured with horizontal double mattresses complementing the individual microsurgical knots. (**e**) Clinical view after one week of healing. (**f**) After 3 weeks of uneventful healing

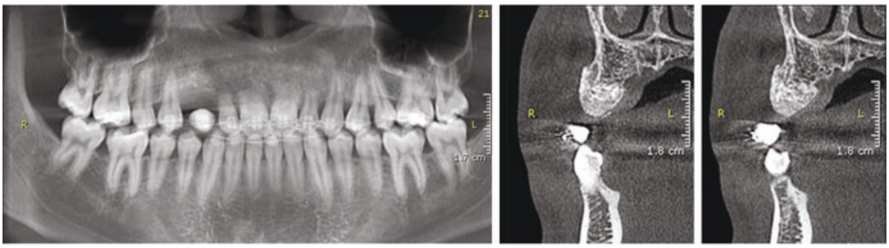


Fig. 85 Cross-sectional and cone-beam panoramic images show healing 9 months after guided bone regeneration

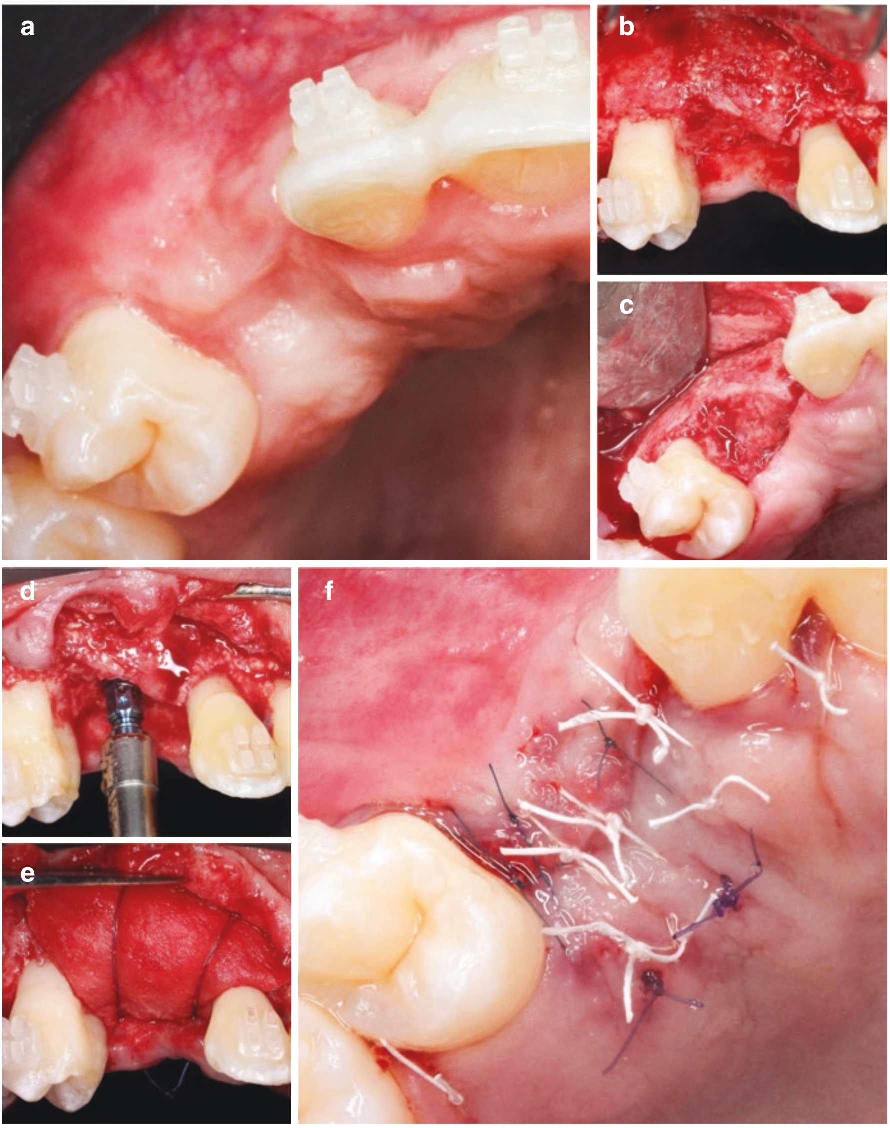


Fig. 86 (**a**) The occlusal image shows healing 9 months after microsurgical guided bone regeneration. (**b**, **c**) Buccal and occlusal views of regenerated bone. (**d**) Buccal view of implant placement. (**e**) Buccal images show that membrane placement after grafting increases buccal thickness. (**f**) The flap is sutured with horizontal double mattresses complemented with individual microsurgical knots

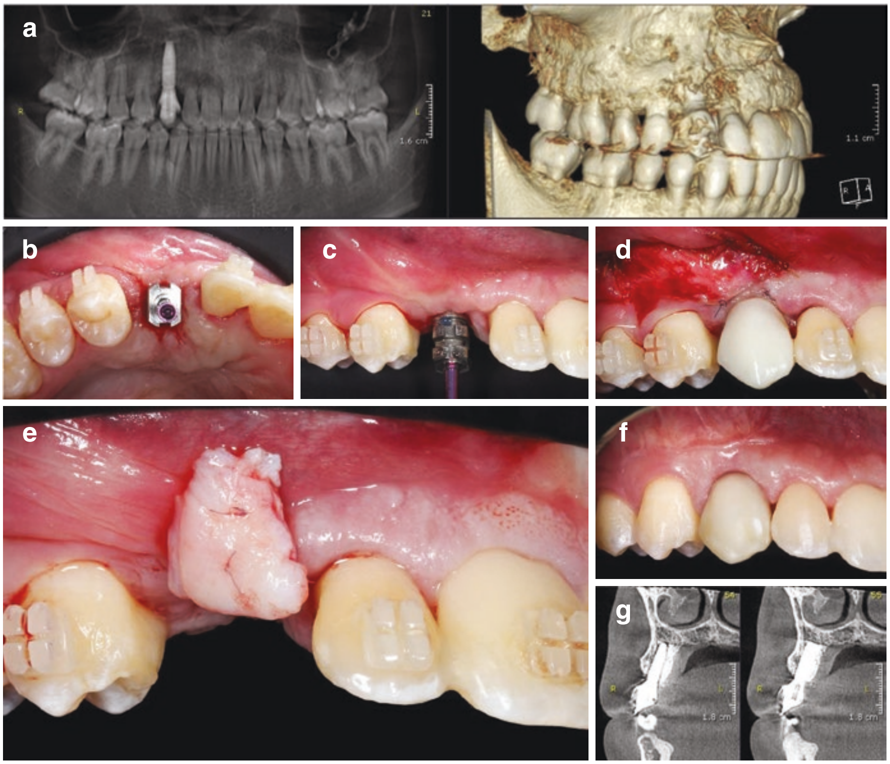


Fig. 87 (**a**) Panoramic and 3D cone beam images show healing four months after implant placement. (**b**, **c**) Occlusal and buccal images show significant mucogingival distortion following guided bone regeneration. (**d**, **e**) Vestibular repositioning and connective tissue graft placement are performed to improve soft tissue architecture, following which temporary restorations are placed. (**f**) Buccal image shows healing 6 months after connective tissue graft placement. (**g**) Three-dimensional cross-sectional images showing the results of microscope-assisted guided bone regeneration

8.3 Soft Tissue Grafts to Increase Keratinized Tissue

Free gingival grafts have a high success rate when discussing keratinized tissue in regenerated sites. Placement of a free gingival graft with an apically positioned flap has good predictability. A partial-thickness flap is raised at the previously augmented site. The extension of the horizontal and vertical incision reaches the regeneration site limits, where the surgeon should reposition the vestibule to recover its depth as the mucogingival loss. The bed is prepared by carefully releasing the tissue and muscular insertion with a microsurgical scalpel and microsurgical tissue scissors, resulting in a receptor bed without movement Videos 26, 27, 28. The technique of procuring the palatal graft depends on the bed's horizontal and vertical extension [86–91]**.** The recommended thickness of the graft is less than 2 mm. After procuring the graft from the donor site, an L-PRF autologous membrane is sutured over the wound to protect the area and aid the healing process Video 29. Adapting and suturing the graft to the receptor site begins with properly tied microsurgical 2 = 2 knots using monofilament suture 7-0 polyamide (Resolon™) at the extremes and polyglycolic acid 8-0, 9-0 (USIOL®) for completion. For apical fixation in the deepening of the vestibule where the muscle tone is strong, we recommend using the glycolic acid copolymer and caprolactone 5-0 (Glycolon™). Videos 30, 31, and 32.

8.4 Allografts, Xenografts, and Their Use

Substitute soft tissue allografts and xenografts can be used to gain soft tissue in regenerative therapy. Videos 12 and 13 However, vestibule repositioning and gain in keratinized tissue demonstrate the superiority of the autologous free gingival graft [85]. Although this material is useful, other evidence-based techniques have also shown to increase keratinized tissue by combining xenografts with autogenous tissue to reduce donor-site morbidity and achieve satisfactory results [87].

9 Ultra-Minimally Invasive GBR Techniques

At present, science and technology are evolving toward increasing the predictability of surgical treatments with minimally invasive procedures. Traditional bone regeneration techniques do not always comply with the requisites of minimally invasive flap surgery because they require flaps of greater dimensions. Bone regeneration microsurgery is minimally invasive because it allows the handling of tissues with greater precision and minimal damage. Periodontal microsurgery shares these attributes with medical microsurgery.

Microsurgery is an example of minimally invasive surgery applied to bone preservation and is performed conservatively without the need to raise flaps. When performed simultaneously with tooth extraction, it helps to preserve the keratinized tissue and achieve closure and fixation with different membranes and contributes to the application of microsurgical techniques to improve the handling of different materials (Video 22).

Other examples of minimally invasive procedures are those in which implant placement is performed simultaneous to regeneration techniques, with placement of bone grafts and membranes using different protocols, [92, 93] and conservative approaches with high precision under the microscope. (Video 33) Another minimally invasive technique proposed in recent years is the Subperiosteal Minimally Invasive esthetic Ridge Augmentation Technique, which consists of small incisions near the defect, creating a tunnel access for the regeneration of bone defects. These tunnels allow the placement of the graft without the need for flap reflection [94].

10 Conclusion

Microscope is an alternative modality that can be useful for clinicians in performing regenerative therapy, and it fulfills the essential requirements of GBR. Microsurgical principles offer tremendous support, facilitating and improving this complex therapy, and microsurgery promises ideal and predictable results.

11 Key Points

1. Guided bone regeneration (GBR) replaces lost tissues with elements to restore normal function and structure for the ideal three-dimensional placement of dental implants.
2. The microscope is a modern surgical accessory and a critical factor for the success of the most complex medical surgeries.
3. The microscope in GBR can aid precision in surgical execution. It has been shown that microsurgery contributes to improved healing and treatment outcomes in other areas of Periodontology.
4. Microsurgery helps develop motor skills by improving surgical capacity, reducing tissue trauma, and contributing to the wound's primary closure.
5. The microscope in GBR improves soft and hard tissue management, offering better visualization during incision placement, flap elevation, preparation of the surgical bed, and flap closure.
6. The microsurgical approach in GBR includes some crucial factors: ergonomic position of the microsurgeon, use of instruments with sufficient handgrip, adequate forearm support to reduce physiological tremor, suture material selection, and adequate tension handling. These are fundamental requirements of microsurgery.

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