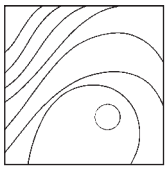
Minimally Invasive Management of Implant-Supported Rehabilitation in the Posterior Maxilla, Part I. Sinus Floor Elevation: Biologic Principles and Materials



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Alveolar bone resorption and maxillary sinus pneumatization occurring after dental extraction in the posterior region of the maxilla may be problematic when planning implant-supported rehabilitation. Various regenerative options are available, including guided bone regeneration, bone block grafts, and lateral sinus augmentation. These procedures are associated with significant complication rates, high morbidity, increased therapy duration, and high cost. Less invasive approaches, such as transcrestal sinus floor elevation, and using short implants have been proposed in an attempt to reduce these drawbacks. The aim of this study is to analyze available evidence to suggest predictable options and identify minimally invasive management of implant-supported rehabilitation in the posterior maxilla. This article concerns biologic mechanisms regulating new bone formation after maxillary sinus augmentation and examines characteristics of available implants and grafting materials to help the clinician select the most rational and convenient surgical approach according to specific situations.
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The alveolar ridge undergoes progressive modifications throughout a patient's entire life. Many factors, including periodontal disease, endodontic lesions, trauma, and tooth extractions, may contribute to the bone resorption process.[1] Additionally, tooth loss in the posterior maxilla may further worsen this problem by promoting maxillary sinus pneumatization, and ridge preservation techniques seem only partially effective in preventing alveolar crest shrinkage.[2,3] Radiographic studies on edentulous ridge dimensions showed that, in this area, bone augmentation procedures for standard implant placement may be necessary in a substantial number of patients.[4]

Numerous surgical techniques and timing protocols have been proposed for implant-supported rehabilitation of posterior atrophic maxillae with limited bone height.[5] Sinus floor elevation with lateral approach was first presented 40 years ago,[6] and consisted of a modification to the Caldwell-Luc sinus revision. The transcrestal approach was developed by Summers in 1994, who proposed an osteotome technique allowing implant placement with limited vertical bone augmentation.[7] Implants inserted after both lateral and transcrestal sinus floor elevation demonstrated satisfactory medium- and long-term survival

rates with a relatively low incidence of postoperative complications.[8]

Even if transcrestal sinus floor elevation is used today when residual bone height is 5 to 8 mm,[9] recent advances in surgical techniques have shown that significant vertical augmentation is possible with a crestal approach.[10,11] The use of short implants (< 8 mm) has been also proposed in the atrophic posterior maxilla to avoid sinus floor elevation and minimize invasivity.[12]

The main objective of minimally invasive therapy is the reduction of morbidity and decreased treatment time and costs. However, the minimally invasive approach must be no less effective than other established treatment methods.

This paper performs a comprehensive analysis of biologic principles and available materials for minimally invasive implant-supported rehabilitations in the posterior maxilla with the aim to help the clinician in selecting the most appropriate surgical approach in the different clinical situations.

New Bone Formation in the Maxillary Sinus

Biologic Mechanisms

The surgical procedure of sinus floor elevation creates a microenvironment with favorable characteristics, according to the main principles of bone regeneration, for primary wound closure, presence of blood supply and undifferentiated mesenchymal cells, space maintenance, and blood clot protection.[13]

In the maxillary sinus cavity, angiogenesis and migration of osteoprogenitor cells from the denuded sinus floor and walls occur as a direct response to surgical trauma. Cytokines and growth factors, usually stored in extracellular matrix, cells, and platelets, are actively released inside the blood clot after the traumatic event, initiating and regulating the complex process of bone healing.[14] The migration of osteoprogenitor cells is promoted mainly by bone morphogenetic proteins (BMPs), platelet-derived growth factor, transforming growth factor-β, insulin-like growth factors, and fibroblast growth factor, while vascular endothelial growth factor is the main initiator of angiogenesis. Recent studies demonstrated that the contribution to bone formation of the sinus membrane appears not to be clinically significant.[15]

Sinus anatomy, surgical technique, type of grafting material, and implant characteristics play crucial roles in influencing the biologic outcomes of sinus floor elevation. Histomorphometric studies reported that the narrower the buccopalatal dimension of the sinus cavity, the quicker the maturation required to achieve a suitable amount of new bone formation, both for lateral[16,17] and transcrestal approaches.[18,19] This is in accordance with the centripetal pattern of new bone formation, originating from lateral and medial sinus walls and from the floor.[20] It still remains unclear if bone maturation could eventually occur in wide cavities after a longer period of time (> 6 months), or if large sinuses represent an unfavorable regenerative environment, indicating a critical size defect.

Surgical techniques should be consistent with biologic principles. The final objective of both the lateral and transcrestal approaches is an adequate detachment of the sinus membrane with consequent exposure of buccal and palatal bony walls. Correct membrane elevation is a fundamental prerequisite for bone regeneration, allowing close contact between grafted material and host bone, favoring graft vascularization and cellular colonization. Numerous studies demonstrated a direct correlation between adequate membrane elevation, new bone formation, and graft dimensional stability.[18–20] Furthermore, an adequate space-making effect should be provided to ensure clot stability in the regeneration area during the early healing period: The use of particulate biomaterials and/or immediate implant placement are necessary to counteract the positive intra-sinus air pressure associated with respiration.

Grafting Materials

During graft maturation, new bone apposition advances with a different gradient for each biomaterial, which influences the osteogenic response of the maxillary bone.[20] Different biomaterials can be used for sinus augmentation procedures. Autologous bone has been considered a gold standard due to its osteogenicity, osteoconductivity, and osteoinductivity[21] (Fig 1). Osteogenesis exploits the presence of resident osteoblasts into the graft to directly generate new

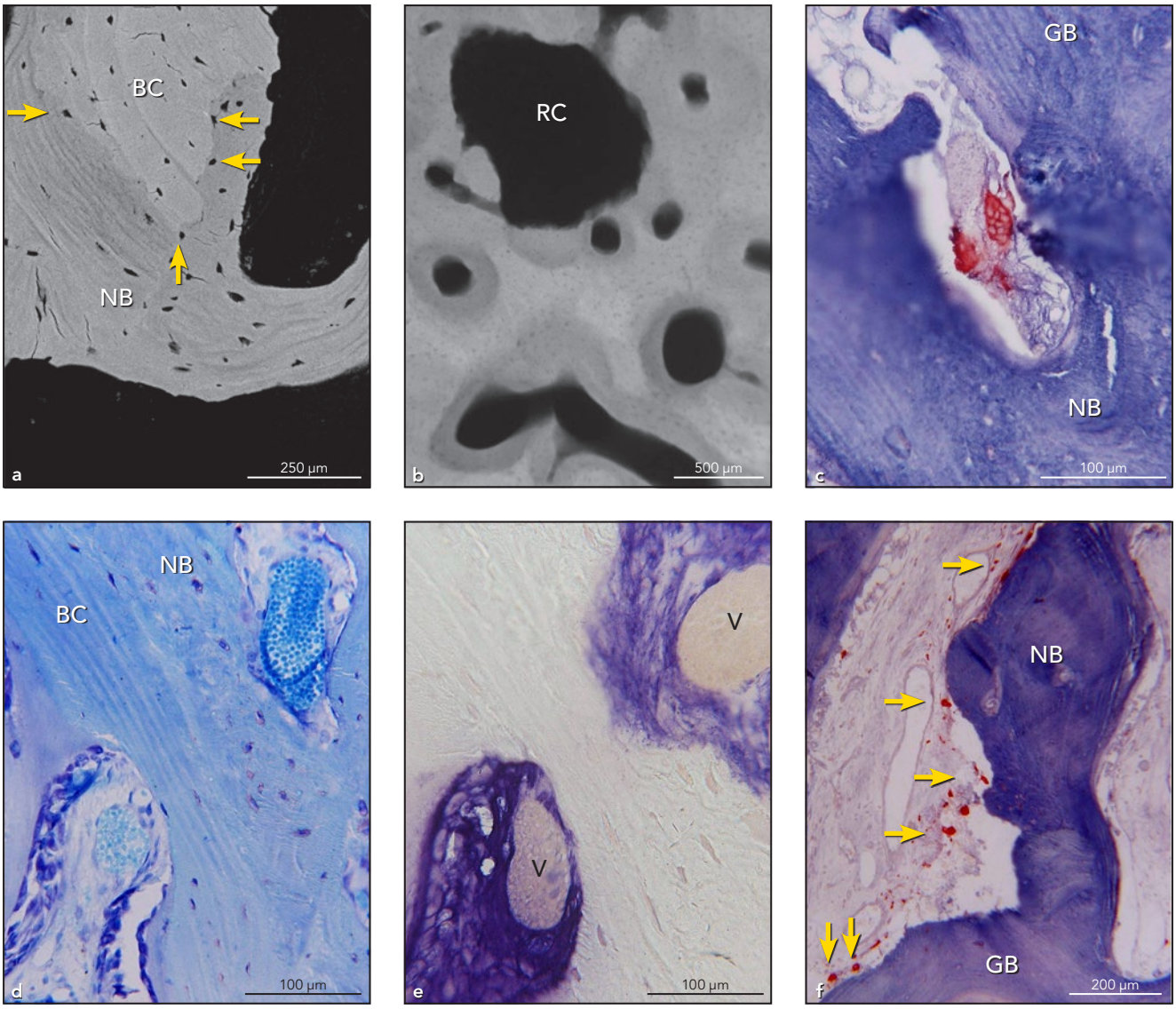

Fig 1 *Autogenous bone.* (a) *Backscattered scanning electron microscope image. Sinus floor augmentation utilizing bone chips (BC) retrieved with a scraper. Notice how the new bone (NB) has osteocyte lacunae* (arrows) *in close vicinity to the BC surface to reestablish interrupted osteocyte interconnections.* (b) *Microradiography. Osteoclasts produce a large resorption cavity (RC) remodeling not only older bone (white or pale gray, grafted or newly formed) but also recently formed bone (dark gray).* (c) *An elongated resorption cavity is produced by two osteoclasts (red) with removal of grafted bone (GB) and NB. Tartrate-resistant acid phosphatase staining.* (d and e) *Resorption cavities, formed at surfaces of BCs and NB in contact with them, each containing a large vessel (V). Notice that the lower cavity osteoblasts lay against the calcified surface. Consequently, the cavity shows greater alkaline phosphatase activity. Toludine blue stain* (d) *and alkaline phosphate stain* (e). (f) *Osteoclasts (red;* arrows*) are removing both GB and NB 5 months after surgery. Tartrate-resistant acid phosphatase staining.*

bone. Osteoinduction is a chemical process due to the presence in the biomaterial of signaling molecules or growth factors (eg, BMPs), capable of inducing the differentiation of local mesenchymal cells into osteoprogenitors.[22] Finally, osteoconduction is a physical process in which a graft simply acts as a scaffold for new bone formation but requires the presence of bone-forming cells, recruited from the host bone.

A histomorphometric analysis comparing the outcomes of nine different biomaterials in lateral sinus augmentation showed that, after a 6-month healing period, autologous bone provided the highest rate of

new bone formation (40.1%).[23] However, harvesting an adequate amount of autologous bone often entails patient discomfort due to a second surgical site, postoperative morbidity, and possible complications.[24] A possible minimally invasive exception is to collect a sufficient quantity of autologous bone by thinning the sinus buccal wall with manual scrapers or ultrasonic tips while performing the antrostomy.[25] Despite the fact that autologous bone provides the greatest amount of vital bone, studies assessing its dimensional stability over time reported contrasting results. A clinical study demonstrated that autologous bone showed the greatest volume reduction during the healing period (up to 45% after 6 months) when compared to other bone substitutes.[26] In contrast, a recent report showed that autologous grafts harvested from intraoral sites exhibited excellent volumetric stability.[27]

Numerous histomorphometric studies have demonstrated satisfactory bone formation (ranging from 25% to 33%) when performing lateral sinus elevation using allograft, xenograft, and alloplastic materials, after a 6- to 12-month healing period (Figs 2 to 4).[28] A recent split-mouth randomized trial has also failed to demonstrate significant variations in terms of new bone formation, comparing xenograft with alloplast in lateral sinus augmentation.[29]

From a clinical point of view, the survival rate of implants inserted into sinuses augmented utilizing only xenograft was reported to be better or similar when compared with cases where only autograft was used.[5]

Timing of Implant Placement

Traditionally, implants are mainly placed in an augmented maxillary sinus after an initial healing period (two-stage procedure). However, placement can be performed contextually with sinus floor elevation when the residual alveolar crest provides adequate primary stability. This approach, first described by Whittaker et al in 1989,[30] reduces morbidity and shortens treatment duration. However, some potential drawbacks should be considered when selecting a one-stage procedure. Risk of intra- and postoperative implant displacement into the sinus cavity exists and is associated with poor bone quality and insufficient residual crest height. In case of accidental displacement, the implant should be removed immediately to minimize risk of infective complications and prevent its migration into adjacent structures, such as ethmoid and sphenoid sinuses, orbit, and cranial fossae.[31] Furthermore, a randomized clinical trial has suggested that a slightly higher risk of implant failure exists when performing one-stage sinus elevations in patients with residual bone height ranging between 1 to 3 mm.[32] From a biologic point of view, the two-stage technique results in a higher percentage of new bone formation than the one-stage technique.[9] A possible explanation involves several biologic factors. First, blood clot contraction during the early phases of healing may result in fibrin network detachment from the rigid titanium implant surface while graft particles are subject to lower forces due to their greater area of surface contact and their inclusion within the clot. Second, when the implant is placed at second-stage surgery, direct contact between the fixture and surrounding bone, even when not completely mineralized, generates bone strain due to slight expansion. Strain signals, which are dependent upon tissue elasticity, are important regulators for new bone formation.[33] Third, if the implant is inserted some months after sinus augmentation, the second surgical trauma acts as a new positive stimulus for angiogenesis and osteoprogenitor cell migration, possibly improving the final quality of the newly formed tissue.

Implant Characteristics

Many implant types with different macro- and microgeometries have been proposed to enhance implant success rates. The incidence of implant failure before functional loading in grafted sinuses was demonstrated to be significantly higher for machined-surface implants as compared to rough-surfaced implants.[5] This finding has a biologic rationale in the increased percentage of bone-to-implant contact of roughened titanium compared to machined surfaces. However, clinical effects of implant surfaces seem to have only a minimal effect on long-term implant survival rates.[34] There is limited evidence suggesting that implants with machined surfaces are less prone to developing periimplant pathologies than implants with rough surfaces (eg, titanium

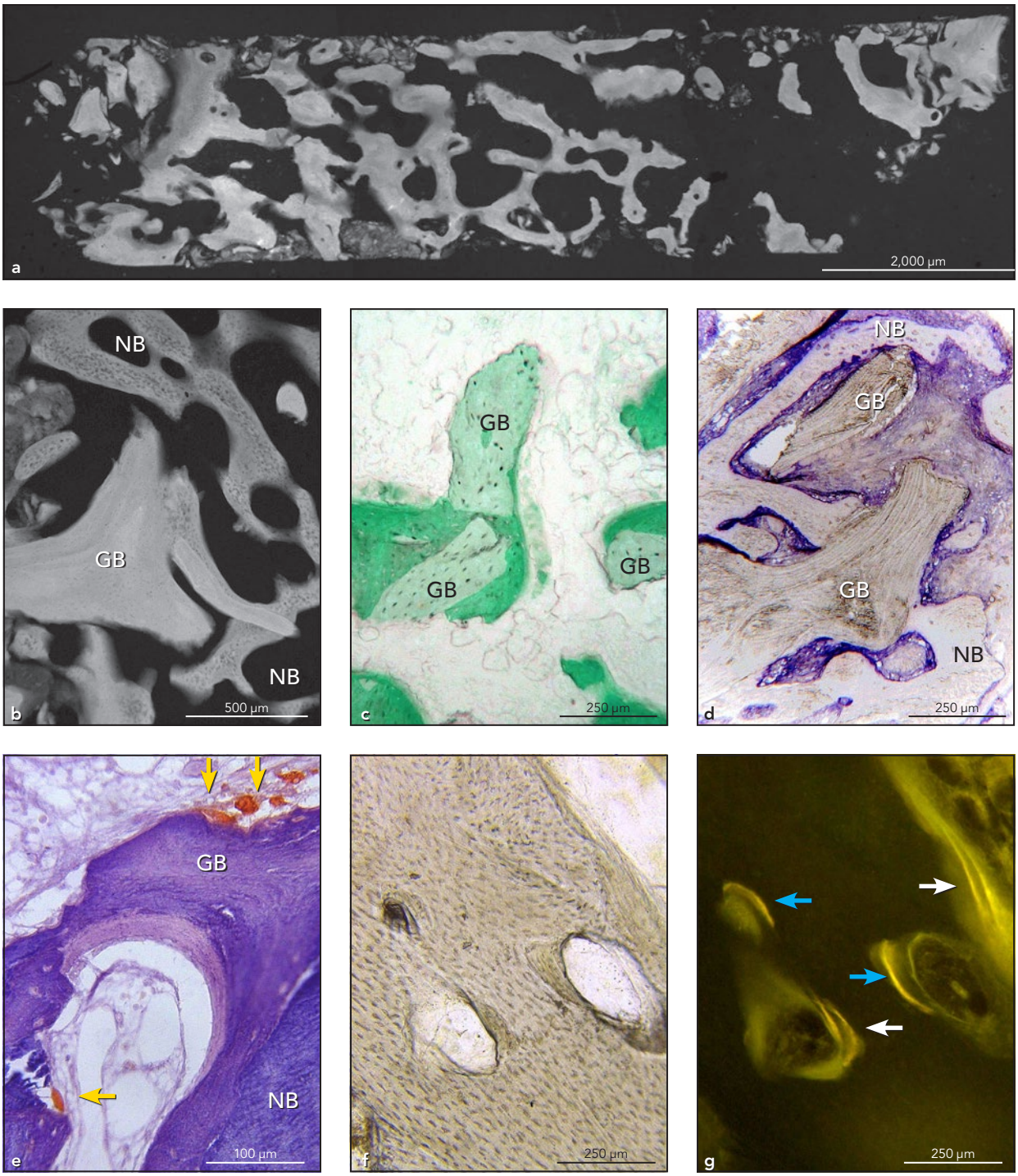

Fig 2 *Homologous bone.* (a) *Microradiography. Bone core biopsy sample of the sinus floor, augmented utilizing mineralized human bone allograft (Puros, Zimmer). Notice the large amount of mineralized tissues (graft + bone = 44.4%) 6 months after surgery.* (b) *Microradiography and* (c) *Fast green FCF staining showing new bone (NB) forms a network interconnecting grafted bone (GB).* (d) *Alkaline phosphatase activity was intense not only in the soft tissue NB but also in soft tissue surrounding GB. Alkaline phosphatase staining.* (e) *Osteoclasts (red; arrows) removed both GB and NB 6 months after surgery and later. Tartrate-resistant acid phosphatase staining.* (f) *and* (g) *The amount of NB (formed between the two tetracycline labels, administered at days 120 and 150; white arrows) was very limited in augmentations utilizing fresh frozen bone. Cyan arrows indicate two sites where bone formation stopped before 150 days. The thick sections in* (f) *and* (g) *are ordinary transmitted light and fluorescent transmitted light, respectively.*

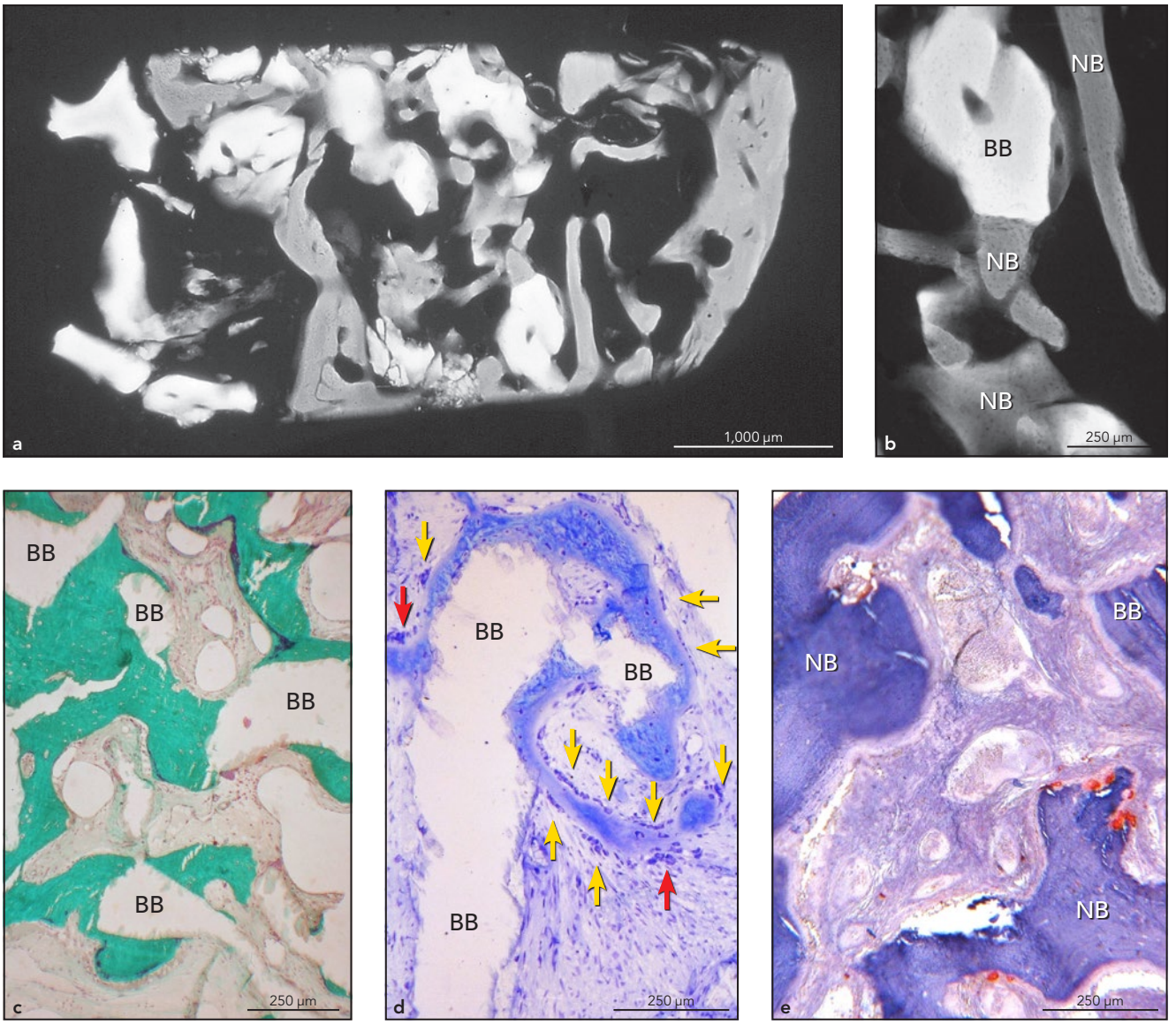

Fig 3 *Heterologous bone.* (a) *Microradiography. Bone core biopsy of sinus floor augmented utilizing bovine bone xenograft (Bio-Oss, Geistlich). Six months after surgery, bone amount was 32.2% and bovine bone xenograft (which can persist for more than 10 years) was 27.0%.* (b) *Microradiography and* (c) *trichrome Gomori staining show new bone (NB) forming a network interconnecting bovine bone (BB).* (d) *Osteoblasts* (yellow arrows) *expand thin bone trabeculae in contact with grafted bovine bone (BB) as osteoclasts (red arrows) simultaneously resorb some trabeculae. Toluidine blue staining.* (e) *Osteoclasts (red) remodel only new bone (NB) but not grafted BB. Tartrate-resistant acid phosphatase staining.*

plasma-sprayed or hydroxylapatite-coated), and no conclusive data are available for minimally and moderately rough textures.[35]

Based upon the behaviors of different surfaces, hybrid implant designs have also been developed in order to better exploit the advantages of both machined and rough surfaces. A machined surface in the coronal region could reduce the risk of peri-implantitis, and an apical rough surface could guarantee rapid and effective osseointegration. Nonetheless, first-generation hybrid implants were partially abandoned due to significantly greater marginal bone loss around machined implant

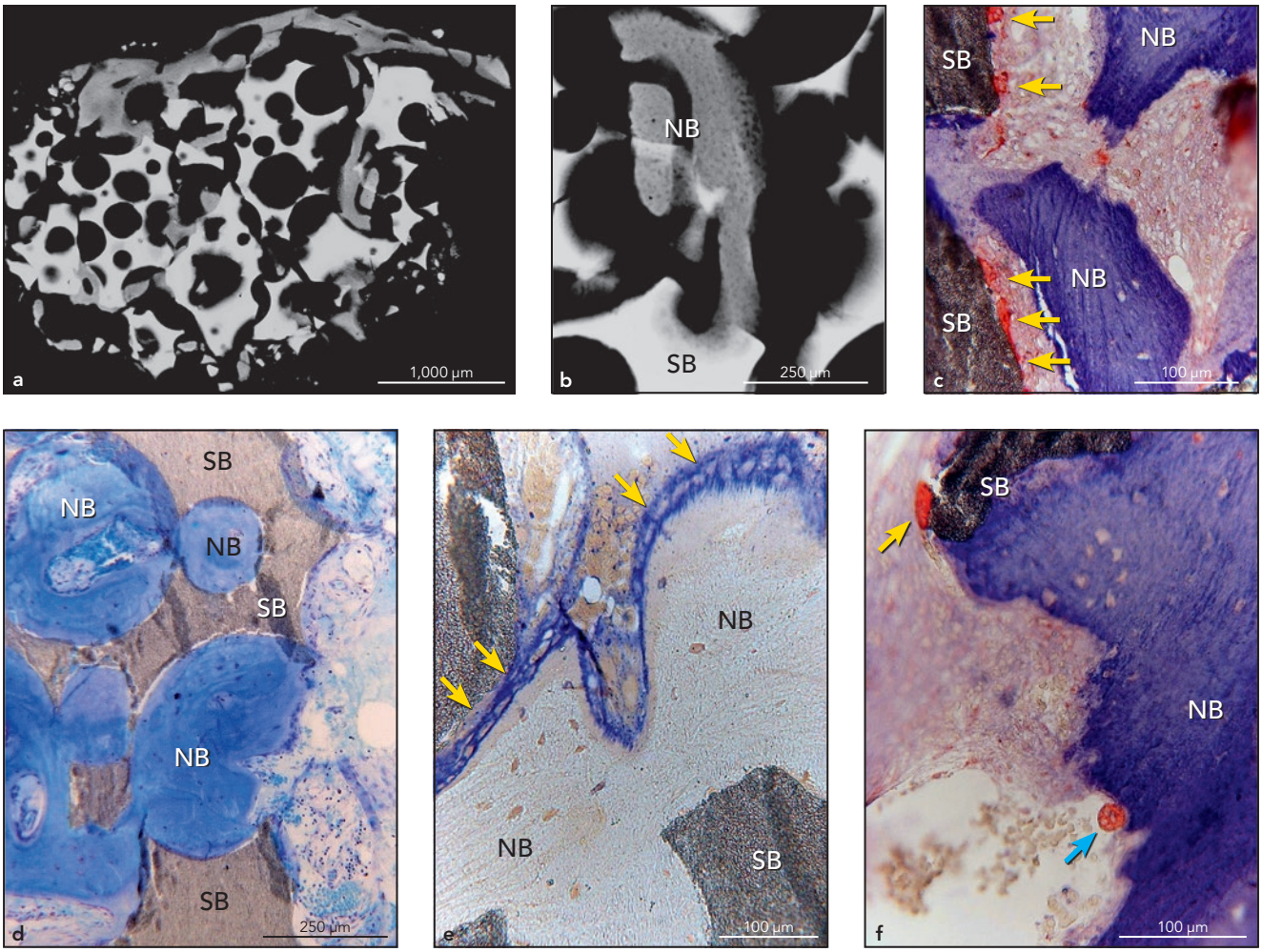

Fig 4 *Synthetic biomaterial.* (a) *Microradiography. Bone core biopsy sample of a sinus floor, augmented utilizing synthetic biomaterial (Hydroxyapatite, Irtec-CNR). Newly formed bone was 20.2% and hydroxylapatite was 26.5%, six months after surgery.* (b) *Microradiography. New bone (NB) forms a network interconnecting synthetic biomaterial (SB), sometimes including small SB fragments.* (c) *Osteoclasts (red; yellow arrows) attempt to resorb SB. Tartrate-resistant acid phosphatase staining.* (d) *NB fills cavities of SB granules and sometimes surrounds parts of them. Toluidine blue staining.* (e) *Osteoblasts* (yellow arrows), *expanding NB in contact with SB, show good phosphatase alkaline positivity 6 months after surgery. Alkaline phosphatase staining.* (f) *One osteoclast* (cyan arrow) *removes NB, while a different osteoclast* (yellow arrow) *attempts to remove SB. Tartrate-resistant acid phosphatase staining.*

necks when compared with fully etched fixtures. More recently, a new generation of hybrid implants has been compared with fully etched and double-sanded implants, revealing identical, very limited marginal bone loss after 1 year of loading.[36] It is interesting to note that scanning electronic microscopy and profilometry reported greater mean roughness values for the coronal machined part of hybrid implants when compared to both coronal and apical parts of etched and double-sanded implants (Fig 5). This unexpected roughness value may positively affect osseointegration but may increase bacterial adhesion and proliferation, even if non–roughness-related factors, such as surface charge and surface energy, can independently influence bacterial adhesion.[36] For this reason, the statement that machined-surface implants are less prone to peri-implantitis than moderately rough implants remains a controversial issue.

Fig 5 *Schematic image of a hybrid titanium implant with a machined surface in the coronal part and sandblasted/double-etched surface in the apical portion.*

Conclusions

Both lateral and transcrestal sinus floor elevations are reliable surgical approaches to regenerate adequate bone volume and allow dental implant placement in the atrophic posterior maxilla. Strict adherence to established surgical protocols is mandatory to optimize clinical outcomes. In particular, adequate sinus membrane elevation and close contact between bone walls and grafting materials are crucial prerequisites for new bone formation in both approaches. Allografts, xenografts, and synthetic biomaterials may be acceptable substitutes for autologous bone, as they promote satisfactory new bone formation (even if less than autograft) and guarantee better volumetric stability. Dental implants can be inserted simultaneously with the augmentation procedure if good primary stability is achievable. Delayed insertion, possibly improving the final quality of regenerated tissue, may be preferable in sinuses with low regenerative potential (a wide sinus which can be considered a "nonhousing" bone defect; elderly and/or low-responding patients). The use of rough implants seems to optimize survival rates, and therefore the new generation of hybrid implants may be a promising alternative to traditional implants, but further investigations are necessary.

Acknowledgments

The authors declare no conflicts of interest.

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