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REVIEW ARTICLE

Treatment alternatives for the rehabilitation of the posterior edentulous maxilla

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1 | INTRODUCTION

The maxilla is an osseous structure located in the middle region of the craniofacial complex that is essentially constituted by two bilateral maxillary bones, which are fused at the sagittal midline by the intermaxillary suture (Figure 1).[1] Each maxillary bone has one body and four processes (i.e., alveolar, frontal, zygomatic, and palatine). The maxillary sinus, the largest of the four paranasal sinuses, is a hollow cavity with an average volume of 12.5 cc that is contained within the body of the maxillary bone (Figure 2).[2] The alveolar process of each maxillary bone houses the maxillary teeth and gives its curved shape to the upper dental arch. Although it is well established that lifelong craniofacial changes affect the contours and relative position of the maxillary bones,[3–5] and that the total volume of the maxillary sinus cavity decreases with age,[6,7] the alveolar process and the maxillary sinus floor do not typically undergo substantial morphological changes within short periods of time as long as the posterior teeth remain in proper function in the presence of periodontal health (Figure 3).

Preclinical and clinical investigations have consistently demonstrated that tooth loss triggers a physiologic response that inevitably results in a variable degree of alveolar ridge remodeling, regardless of the location within the arch.[8–10] Clinical studies on tooth loss due to periodontitis have shown that maxillary molars are the tooth type most frequently lost,[11–13] likely because of more difficult access to perform adequate oral hygiene compared to anterior teeth and specific anatomical characteristics that may facilitate disease progression (e.g., furcations).[14] Following extraction of teeth in close proximity to the maxillary sinus floor, in parallel to a process of alveolar bone atrophy,[15] the antral cavity may expand both inferiorly (coronally) and laterally in a phenomenon known as maxillary sinus pneumatization.[16] Interestingly, a radiographic study revealed that postextraction bone remodeling in the posterior maxillary sextant can be mostly attributed to alveolar ridge resorption, while changes in the position of the maxillary sinus floor are generally less pronounced, at least up to 5 years after tooth extraction.[17]

Although a shortened dental arch, defined as the type of dentition with reduced or even absence of the molars and/or premolars,[18] has been proven a viable alternative to tooth replacement therapy in some cases,[19,20] rehabilitation of the posterior edentulous maxilla with fixed implant-supported dental prostheses is often requested

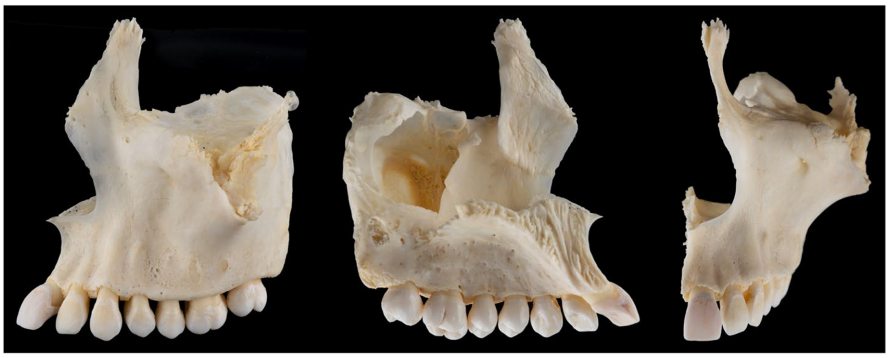

FIGURE 1 Different perspectives of a dry maxillary bone with its corresponding teeth. From left to right, lateral, medial, and frontal view. Note in the medial view the absence of part of the internal wall of the maxillary sinus cavity, which allows for partial visualization of this anatomical structure that is contained within the body of the maxillary bone.

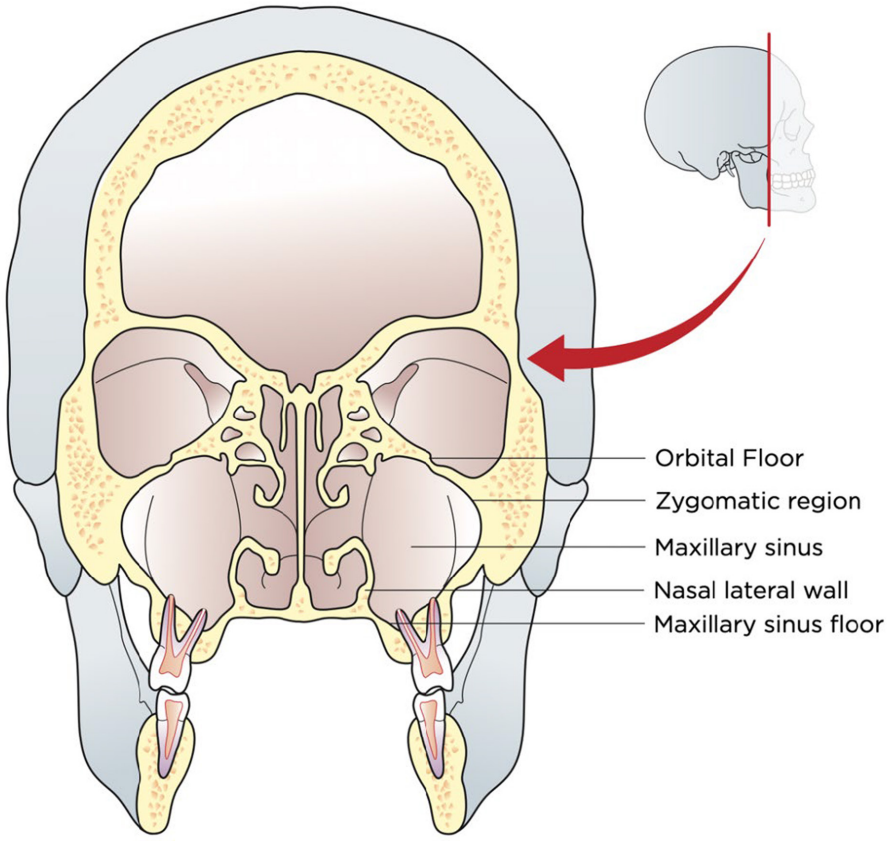

FIGURE 2 Frontal section of the craniofacial complex. Note the anatomical boundaries of the maxillary sinus. (Adapted with permission from Avila-Ortiz et al.[1]).

by patients whose quality of life is affected by the lack of teeth in this region.[21,22] However, implant placement in the posterior segment of the maxilla may represent a challenge for dental practitioners due to difficult surgical access and limited bone availability (Figure 4).

This review is focused on providing a concise and practical overview of therapeutic alternatives for the rehabilitation of posterior edentulous maxillary sectors, including scenarios in which conventional implant placement may not be feasible due to anatomical constraints.

2 | TREATMENT ALTERNATIVES

2.1 | Maxillary sinus floor augmentation

Maxillary sinus floor augmentation has been defined as a surgical intervention aimed at gaining bone volume in edentulous, atrophic posterior maxillary segments by displacing the existing sinus floor in an apical direction with the purpose of facilitating implant placement in a restoratively driven position.[1] Analogous terms to maxillary sinus floor augmentation are maxillary sinus floor lift, maxillary sinus floor elevation, and maxillary sinus grafting, among others. Maxillary sinus floor augmentation is a generally effective and predictable implant site development modality that is associated with high implant survival rates.[23–26] However, given the ample anatomical variability of the maxillary sinus and related structures (e.g., size of the antral cavity, vascular and neural networks, bony septa, and residual subantral bone height), as well as, the severe consequences of some possible intra- and postoperative complications (e.g., profuse hemorrhage and subacute sinusitis), aside from proper execution of the surgical technique, meticulous planning and case selection are crucial to achieving a favorable outcome.[1]

Maxillary sinus floor augmentation is frequently indicated to facilitate standard-length (≥8 mm) implant placement in the posterior maxilla, particularly when bone height is insufficient due to extensive

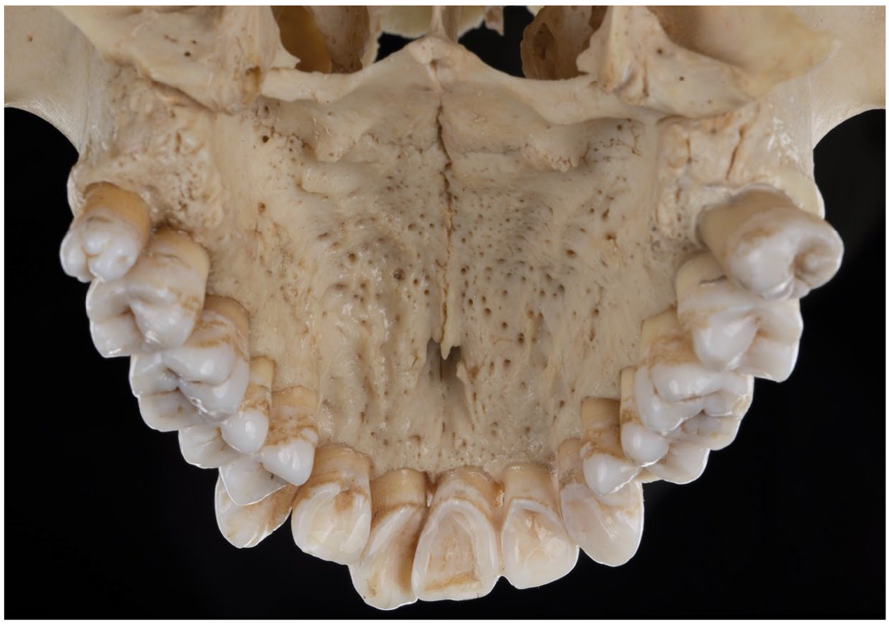

FIGURE 3 Posterior view of the maxillary arch of a dry skull, showing the relationship of the teeth with the alveolar bone.

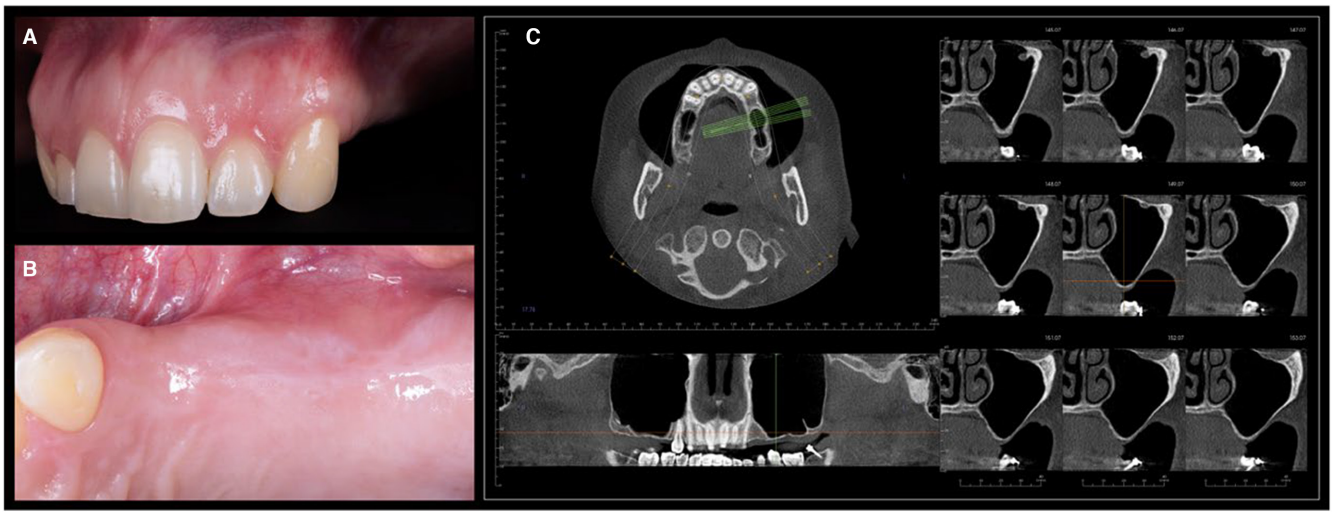

FIGURE 4 Oblique (A) and occlusal (B) intraoral photographs, and cone-beam computed tomography imaging (C) of the upper left region of a patient presenting bilateral bone atrophy associated with posterior maxillary edentulism. (Adapted with permission from Avila-Ortiz et al.[1]).

antral pneumatization after postextraction bone remodeling or other etiologies, such as trauma, resective surgery, and congenital hypodontia.[27] The decision of whether to use a bone graft material in maxillary sinus floor augmentation procedures is mainly determined by technical preferences and anatomical factors. While graftless maxillary sinus floor augmentation has been documented as a viable alternative that is associated with satisfactory outcomes,[28] this approach requires simultaneous placement of implants protruding into the sinus cavity to tent the Schneiderian membrane and, therefore, create an adequate space for blood clot formation, which is not always feasible and may not result in a sufficient amount of new bone formation. To overcome these limitations, the use of bone graft materials is generally indicated in maxillary sinus floor augmentation. It is important to note that maxillary sinus floor augmentation may be combined with simultaneous alveolar ridge augmentation to allow for implant placement in a favorable prosthetic position in situations where severe horizontal and/or vertical ridge atrophy exists.[29,30]

Maxillary sinus floor augmentation involves partial elevation of the respiratory mucosa that lines the antral cavity (i.e., Schneiderian membrane) to displace the sinus floor apically. This can be accomplished with either a transalveolar,[31,32] a lateral window,[33] a crestal window,[34,35] or a palatal window approach,[36,37] with or without the use of a bone graft material or space filler, and with or without simultaneous implant placement (Figure 5). In contemporary dental practice, the most employed maxillary sinus floor augmentation approaches are the lateral window approach, with simultaneous or delayed implant placement, and the transalveolar approach, which usually involves simultaneous implant placement.

Maxillary sinus floor augmentation via a *lateral window approach* is indicated for the prosthetic rehabilitation of edentulous spaces in

the posterior maxilla presenting very limited residual bone height, typically ≤5 mm. While the origin of the maxillary sinus floor augmentation technique in dentistry remains controversial, the first formal description of the lateral window approach was published by Boyne and James in 1980.[33] As described elsewhere,[1] this surgical intervention typically involves the elevation of a trapezoidal mucoperiosteal flap that passes the mucogingival junction in order to expose the lateral wall of the maxillary sinus, near the zygomatic process. Subsequently, the access window is delineated, which can be performed using a round diamond bur attached to a high-speed rotary handpiece, piezoelectric equipment, and/or a manual bone scraper, for example. Once exposed, the maxillary sinus membrane is detached from the bony walls using sinus membrane elevators and/or blunt piezoelectric tips with care to avoid perforations and overextension beyond the region planned for bone augmentation. In sites presenting sufficient alveolar bone height to allow for simultaneous implant placement, usually between 3 and 5 mm,[1] the implant osteotomy should be completed at this point, paying close attention to protect the already elevated sinus membrane from the action of the drills. Then, unless a graftless approach is followed,[38,39] the bone graft or filler of choice is distributed in the compartment created after the elevation of the sinus membrane, gently packing the material against the most medial and mesial region of the sinus compartment first, followed by implant placement, if indicated, and, finally, completing the process by grafting towards the lateral aspect until the material is leveled with the bony surface. The lateral window may be covered with a barrier membrane to promote bone formation according to the principles of guided bone regeneration,[40] and then the flap is repositioned and sutured to achieve primary closure, unless a one-stage implant placement protocol involving the use of transmucosal components is followed (Figure 6).[41]

The *transalveolar approach*, also known as transcrestal, was originally described by Tatum in 1986 as an alternative to the lateral window approach to simplify the technique and minimize the occurrence of complications by reducing surgical time and trauma.[31] This specific maxillary sinus floor augmentation approach is generally indicated in sites presenting a sufficient amount of subantral alveolar bone that would allow simultaneous implant placement. According to the technical modifications proposed by Summers in 1994,[32] following the elevation of a full-thickness flap to visualize the bone crest, a small osteotomy is made through the remaining alveolar bone with care to avoid perforating the respiratory mucosa that lines the maxillary sinus floor. This pilot osteotomy opens a pathway for the insertion of osteotomes of increasing diameter by pushing and tapping with a surgical mallet to both increase the density of the surrounding alveolar bone and to progressively elevate the Schneiderian membrane vertically, creating an apical space for optional bone grafting and subsequent implant placement (Figure 7). An important limitation of the transalveolar approach is the possibility of inadvertent perforation of the maxillary sinus membrane due to limited visibility. This may be associated with severe complications if bone graft particles are projected into the antral cavity and cause blockage of the ostium, which can result in an episode of subacute sinusitis.[42] However, a study using intrasinusal endoscopy demonstrated that, if the technique is carefully executed in the presence of favorable local anatomy, the sinus floor may be elevated up to 5 mm without perforating the membrane.[43] Although the fundamentals of the technique originally described by Summers still prevail, subsequent modifications of the transalveolar approach have been proposed since the mid-1990s involving the use of different devices, such as elastic balloons,[44] piezoelectric tips,[45] bone reamers,[46] hydraulic instruments,[47] and specially designed drills.[48,49]

Graft material selection is an important aspect of clinical decision-making when planning and executing maxillary sinus floor augmentation surgeries. The first graft material documented for maxillary sinus floor augmentation was autogenous bone.[33] While it generally rendered favorable outcomes, the use of autogenous bone in maxillary sinus augmentation has two major drawbacks. First, the need to harvest a variable amount of bone, typically between 0.5 and 5 cc,[50] from a second surgical site. This increases the surgical time and the risk of intraoperative complications and postoperative morbidity. Second, the high biodegradation rate associated with particulate autogenous bone,[51] which may exceed the rate of new bone formation during the consolidation phase and result in a suboptimal bone volume gain outcome. To overcome the limitations of autogenous bone grafts, the use of bone substitutes (i.e., xenografts, allografts, and alloplastic materials), alone or in combination with bone autografts, has become the standard for the performance of maxillary sinus floor augmentation procedures in contemporary clinical

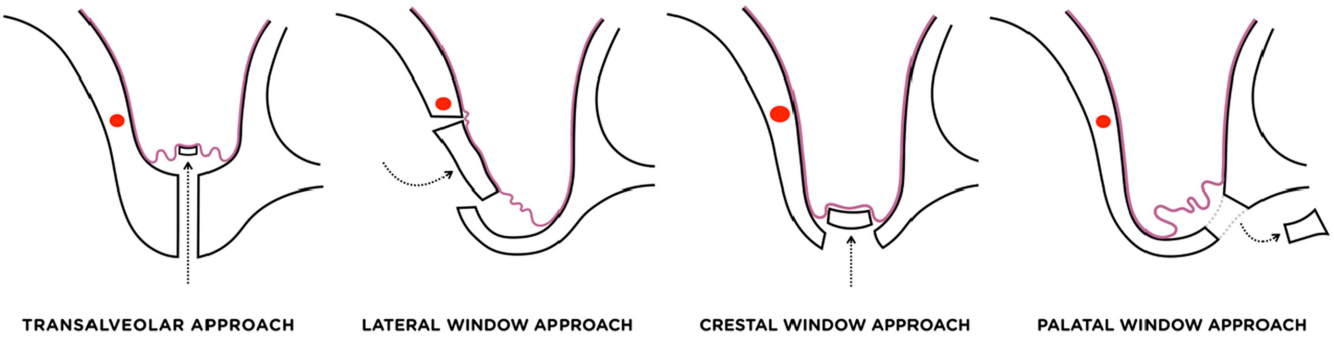

FIGURE 5 Modalities of maxillary sinus floor augmentation. (Adapted with permission from Avila-Ortiz et al.[1]).

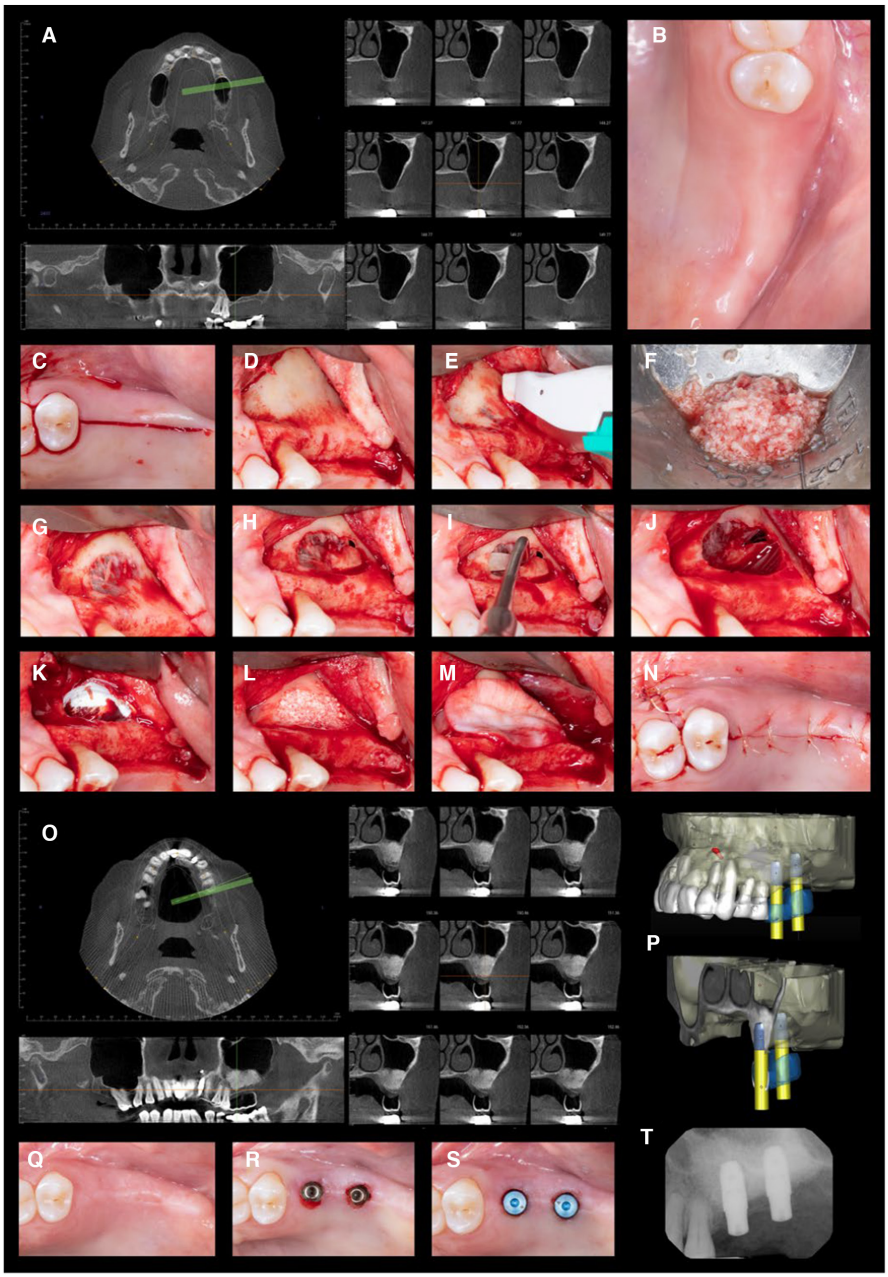

FIGURE 6 Sequence of a case of MSFA via a lateral window approach and delayed implant placement. (A) Radiographic study of the baseline scenario. (B) Intraoral occlusal view of the edentulous segment. (C) Supracrestal and vertical releasing incisions. (D) Mucoperiosteal flap elevation. (E) Bone scraper is used to harvest autogenous bone from the lateral sinus wall. (F) Mix of autogenous bone (~20%) and bovine xenograft particles (~80%). (G) Aspect of Schneiderian membrane as the lateral window access is created. (H) A perforation was noticed on the upper and posterior corner of the window. (I) A sinus membrane elevator was applied on the opposite side of the perforation. (J) The perforation got slightly larger upon complete elevation of the membrane. (K) An absorbable porcine collagen membrane was used to seal the perforation. (L) The bone graft mix was used to fill the subantral space. (M) Another porcine collagen membrane was applied to cover the window. (N) Primary closure was achieved. (O) Radiographic study of the augmented area after 6 months of healing. (P) Virtual planning for static computer-aided implant placement. (Q) Occlusal view of the site. (R) Implants were placed following a flapless approach through the surgical guide. (S) Primary stability was achieved. Healing abutments were delivered. (T) Control periapical radiograph obtained immediately after implant placement. (Adapted with permission from Avila-Ortiz et al.[1]).

practice. Over the past three decades, histologic and histomorphometric analyses of human biopsy specimens obtained at different time points from sinuses augmented with bone substitutes have shown that most graft substitutes are biocompatible, osteoconductive, and present a low biodegradation rate. To benefit from the inherent properties of autogenous bone (i.e., osteoconductive, osteoinductivity, and osteogenicity) while reducing the need to harvest large amounts of native bone and leverage the low resorption rate of some bone substitutes, such as bovine xenograft or cortical allograft particles, some authors have advocated to use them in combination, with a larger proportion of a bone substitute (e.g., 80:20 ratio).[52,53] Although this approach makes biological sense, several systematic reviews on this topic have revealed that, from a clinical standpoint, no specific bone graft material or combination thereof is patently superior for maxillary sinus floor augmentation.[24,26,54–57] In recent years, to stimulate oral tissue repair/regeneration and increase the predictability of conventional therapeutic approaches involving the use of bone grafts, some clinicians have leveraged bioengineering strategies, including the use of biologics. The effect of biologics, such as autologous blood-derived products, enamel matrix derivatives, recombinant human platelet-derived growth factor BB or recombinant human bone morphogenetic protein 2, in maxillary sinus floor augmentation has been evaluated in preclinical and clinical settings. However, as concluded in the 2022 American Academy of Periodontology Best Evidence Consensus on the use of biologics in periodontal practice, there is limited evidence to support that the use of the previously mentioned biologics, either as a monotherapy or in combination with bone graft materials for implant site development purposes, including maxillary sinus floor augmentation procedures, renders superior clinical and radiographic outcomes when compared

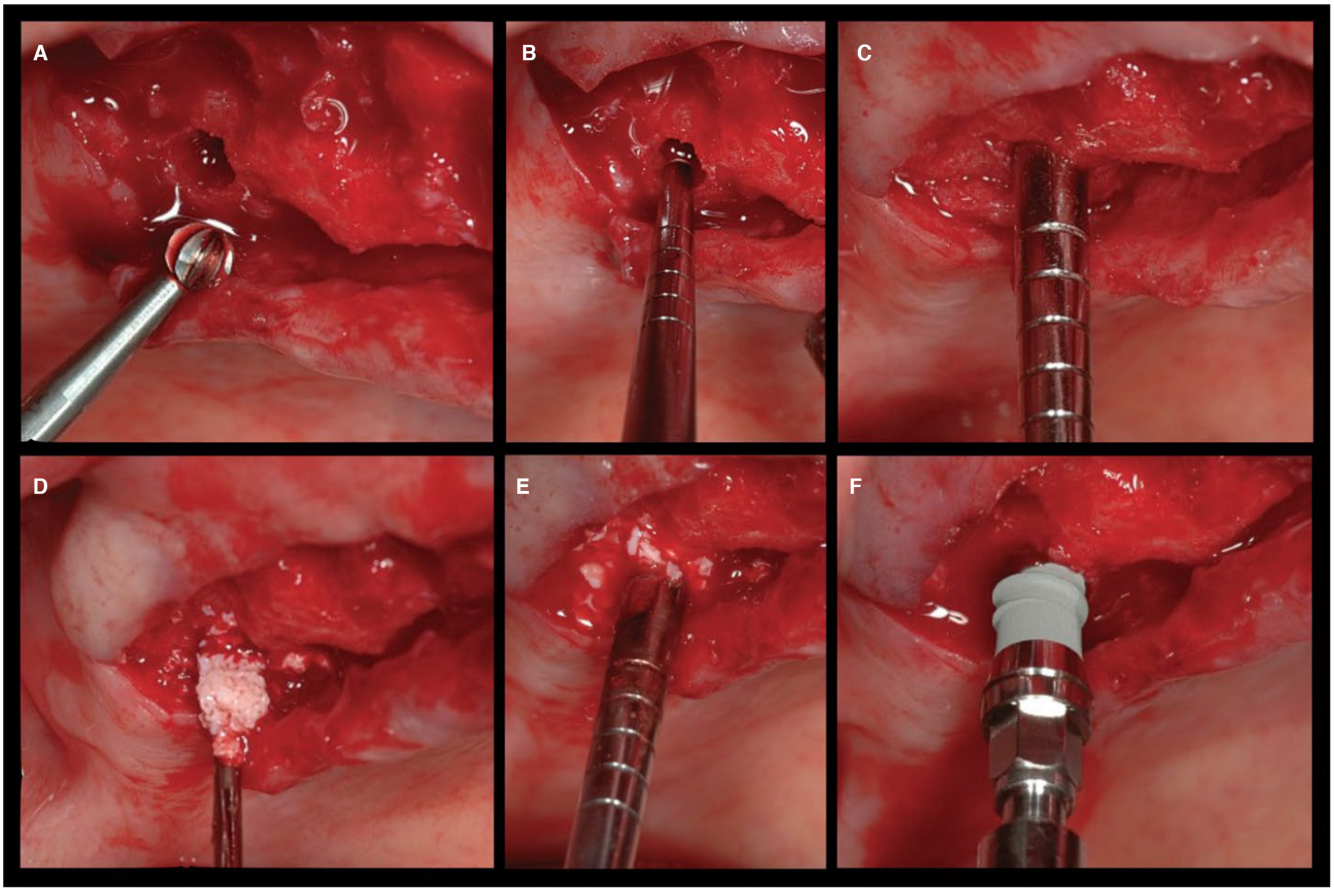

FIGURE 7 Sequence showing the essential steps of a transalveolar MSFA procedure with simultaneous implant placement. Upon elevation of a full-thickness flap, a round bur is used to mark the osteotomy site and facilitate the insertion of the first osteotome (A). First osteotome is progressively inserted with gentle malleting to create a greenstick fracture of the sinus floor (B). An osteotome of wider diameter is inserted to expand the osteotomy (C). Bovine xenograft particles are placed into the site after the osteotomy is created (D). The final osteotome is used to carefully push the bone grafting material in the subantral space (E). The implant is inserted once the grafting procedure is completed (F). (Adapted with permission from Avila-Ortiz et al.[1]).

with conventional interventions.[58] However, the adjunctive use of these biologics seems to translate into favorable histomorphometric outcomes (i.e., mineralized tissue formation observed in bone core biopsies).[59] It was also noted that, based on expert opinion,[58] biologics can promote soft tissue healing and bone formation, which may be particularly beneficial in situations where poor or impaired healing outcomes are anticipated (e.g., diabetic and osteoporotic patients).[60] Another advantage of some biologics, particularly autologous blood-derived products, (e.g., platelet-rich fibrin), is that the handling properties of particulate bone graft materials can be enhanced (the so-called "sticky bone") and contribute to local hemostasis. However, the body of evidence is still limited to establishing solid clinical guidelines on the use of these products for maxillary sinus floor augmentation in daily practice.[61] In conclusion, there is a need for targeted, well-designed long-term studies evaluating the performance of different bone graft materials and tissue engineering strategies (e.g., biologics and cell therapy) in maxillary sinus floor augmentation to generate new knowledge that may aid clinicians in discerning what surgical protocol may render more favorable and predictable results in specific clinical scenarios.

Delayed implant placement after maxillary sinus floor augmentation provides an opportunity to obtain a human bone core biopsy for histologic and histomorphometric analysis. This allows us to gather valuable information about the biological characteristics of the substrate that will surround the implant fixture. Aside from different patient-related local and systemic variables, the properties of the biomaterial(s) employed may largely influence the healing process and the biological features of implant site, which can subsequently determine whether successful osseointegration is achieved and the fate of the peri-implant tissues in the long-term. Nevertheless, it is important to recognize that, independently of the bone graft material applied, osteogenesis is ultimately induced by the host, and it is site dependent. Therefore, the structural and biological features of bone samples obtained after the use of different bone graft materials for maxillary sinus floor augmentation should be compared to those of pristine (native) bone core biopsies from the posterior maxilla to better understand the outcomes of therapy from a biological standpoint. In this regard, Ulm and coworkers reported that the mean percentage of trabecular mineralized tissue observed in core biopsies obtained from the posterior maxillary region (first

molar area) in cadaver heads ranged between 17.1% in females to 23.4% in males.[62] In another study, Trisi and Rao found that the average proportion of mineralized tissue in D4 bone core biopsies[63] harvested using a small trephine (2 × 5 mm) in the posterior segments of the maxilla was 28.28%.[64] Interestingly, other authors have found mineralized tissue values between 45% and 47% in bone core biopsies also obtained from the posterior maxilla, but using larger trephines.[65,66] Differentially, Galindo-Moreno and coworkers not only presented histomorphometric data but also descriptive histological information pertaining to the presence of osteoid lines and other cell populations.[65]

The literature is flooded with reports on the analysis and comparison of the outcomes obtained after the use of different types of biomaterials, biologics, autogenous bone, and combinations thereof in maxillary sinus floor augmentation. It is generally acknowledged that no specific biomaterial or combination predictably leads to obtaining superior structural and biological properties that are comparable to those typically exhibited by native bone in those anatomical locations. However, some differential patterns have been identified as a function of the features of the biomaterial(s) employed, such as surface microroughness, porosity, and mineral content, among others, which can play an important role in biological processes such as neoangiogenesis, osteogenic cell migration, attachment and differentiation, and biodegradation. Table 1 displays relevant information pertaining to the histomorphometric analysis of samples obtained from pristine bone and sites that underwent augmentation with different bone graft materials, including autogenous bone and substitutes.

Aside from general postoperative guidelines applicable to any intraoral surgical procedure (i.e., keep the surgical area undisturbed, maintain a well-balanced diet, and stay hydrated, while avoiding the intake of hot foods and beverages), patients undergoing maxillary sinus floor augmentation should receive additional specific instructions: Avoid strenuous physical activity such as swimming, aerobics or running for the following 7–10 days; Do not use a straw to drink; Try to avoid sudden pressure changes (e.g., taking an airplane); If blowing your nose or sneezing is inevitable, try to do it gently and with your mouth open. To prevent a post-surgical infection, the antibiotic prescription is generally recommended (e.g., amoxicillin 500 mg TID for 7 days; or, if allergic to penicillin, clindamycin 300 mg TID for 10 days, starting 2 days prior to the surgery). Non-steroidal anti-inflammatory medication (e.g., ibuprofen 600 mg TID) or analgesics (e.g., acetaminophen/paracetamol 500 mg TID) should also be prescribed to control postoperative swelling and discomfort over the first 3–7 days after surgery. The prescription of opioids is usually not necessary to control postoperative pain and discomfort and must be reserved for specific situations in which the first line of therapy is not effective. If there is no medical contraindication, prescription of corticosteroids in decreasing daily doses (e.g., dexamethasone 8 mg QD the day of the surgery, 6 mg QD the day after the intervention, 4 mg QD 2 days after the intervention, and 2 mg QD 3 days after the surgical procedure) may also be considered to reduce postoperative edema and other sequelae, such as trismus.[67] Subjects should return between 10 and 14 days after the surgical intervention for suture removal, careful plaque and debris removal, and reinforcement of postoperative instructions.

A relevant aspect pertaining to maxillary sinus floor augmentation is the occurrence and management of intra- and postoperative complications. According to current literature, the most frequent intraoperative complication in maxillary sinus floor augmentation surgery is the perforation of the Schneiderian membrane. This can occur in any modality of maxillary sinus floor augmentation (i.e., transalveolar, crestal, palatal, and lateral) and it has been reported to be as frequent as one in five cases of the lateral window approach.[23,26] If not properly managed, a sinus membrane perforation increases the risk of postoperative sinusitis and maxillary sinus floor augmentation failure due to displacement of the graft material. Sealing the perforation with an absorbable barrier membrane or a fibrin construct to avoid extravasation of bone graft material particles into the antrum is a commonly employed method to manage this complication (Figure 8). It is generally recommended to abort the procedure if the perforation cannot be sealed intraoperatively due to the size and extent of the damage to the Schneiderian membrane.[68] The second most common complication is abnormal postoperative bleeding (14.5%), which is typically associated with damage to the posterior superior alveolar artery,[69] while the occurrence of overall postoperative infections and subacute sinusitis[70] is generally very low, at approximately 1.0% and 0.2%, respectively.[23,71] Subacute sinusitis typically manifests between 3 to 7 days after the surgical intervention. This complication is typically associated with severe suborbital pain and may lead to complete graft failure or secondary infections that can potentially spread beyond the antral cavity into the orbital region or even to the brain.[72] For that reason, effective and timely management of acute postoperative infections is crucial. When postoperative subacute sinusitis is identified, it is recommended to perform a surgical entry to carefully drain, debride, and remove the entire graft material from the sinus cavity, plus administration of high doses of wide-spectrum systemic antibiotics (e.g., amoxicillin or levofloxacin) for 7–10 days and close monitoring until symptoms resolve.

2.2 | Short implants

The use of short dental implants represents one of the therapeutic options for the rehabilitation of the posterior edentulous maxilla while avoiding possible risks, intra- and postoperative complications, and a longer recovery time derived from the execution of advanced bone augmentation procedures, such as maxillary sinus floor augmentation, particularly in regions of reduced bone height (Figure 9).[73,74] The threshold of length that defines a short implant is still subject of discussion in the scientific literature,[74] while some authors consider this value to be <10 mm, others draw the line at <8 mm, or even at ≤6 mm to define extra-short implants.[75,76]

TABLE 1 Histomorphometric analysis of samples obtained from pristine bone and sites that underwent augmentation with different bone graft materials.

	Pristine bone		Biomaterials					
			Xenogeneic		Allogeneic			Alloplastic
	Pristine bone[65]	Pristine bone[192]	Bovine (Bio-Oss®)[192]	Bovine (Creos®) submitted 2022	Cortical particles (Puros®)[193]	Corticocancellous particles (MinerOss®)[192]	Corticocancellous particles (MinerOss®)[193]	TCP + HA (Osteon®)[194]
Tissue compartments								
Mineralized tissue	45.73%	45.20%	37.87%	27.46%	39.5%	27.59%	31.9%	34.93%
Non-mineralized tissue	51.23%	54.45%	40.66%	52.56%	51.8%	52.16%	47.7%	55.23%
Biomaterial remnant	–	–	21.45%	19.98%	8.6%	20.58%	18.9%	9.82%
Cell types and vessels per mm^2								
Osteoblasts/mm^2	247.31	23.38	101.84	60.93	0.19	49.73	52.2	30.86
Osteocytes/mm^2	1575.28	159.67	113.71	182.80	161.8	95.52	100	134.67
Osteoclasts/mm^2	48.38	4.03	19.70	53.76	2.46	1.97	2.25	15.57
MSCs/mm^2	N/A	17.53	121.50	267.03	14.1	28.23	127.8	239.69
Osteoid lines	N/A	2.30	18.20	5.25	8.5	3.40	2.11	N/A
Vessels/mm^2	N/A	15.34	32.26	90.50	2.65	10.56	31.4	25.62

Note: In yellow, note that no biomaterial or combination of them resulted in greater mineralized tissue formation than pristine bone.

Abbreviations: AB, Autogenous bone; BCP, Bicalcium phosphate; HA, Hydroxyapatite; MSCs, Mesenchymal stem cells; PLGA, polylactic-co-glycolic acid; TCP, Tricalcium phosphate.

Short dental implants may be employed as part of multiple restorative strategies to rehabilitate long edentulous spans, including the use of short implants in the more atrophic region in combination with longer implants inserted in sites presenting enough residual alveolar bone. Aside from high levels of patient acceptance and satisfaction[77] and favorable cost-effectiveness, mainly due to the reduced surgical invasiveness and the avoidance of ancillary bone augmentation procedures, there is a substantial amount of scientific data to support the use of short dental implants in contemporary dental practice. Although earlier studies on this topic reported lower short-term (up to 5 years) survival rate of short implants compared to standard length implants,[78,79] more recent evidence indicates that the clinical performance of short implants placed in posterior maxillary segments is comparable or even superior to regular implants placed after or in concomitance with bone augmentation procedures.[80–83]

A randomized clinical trial conducted by Taschieri and colleagues involved the treatment of 27 patients that received short dental implants (6.5–8.5 mm) in the posterior maxilla with no additional bone augmentation compared with a control group consisting of 25 patients that underwent lateral maxillary sinus floor augmentation and received delayed standard implants (≥10 mm). After a follow-up period of 72 months, no implant failures nor significant differences in marginal bone level changes were observed between groups. Notably, the cohort that received short dental implants reported lower degrees of postoperative pain, inflammation, and other adverse postoperative effects together with a faster recovery of normal activity compared to patients in the control group.[84]

A retrospective analysis aimed at assessing the performance of short implants (≤8 mm) as a function of different factors, including crown-to-implant ratio and prosthetic design (i.e., splinted versus non-splinted restorations). A total of 180 short implants placed in 130 patients were evaluated after 3–7 (mean = 4.2) years of follow-up. Four implants in four different patients failed due to severe peri-implantitis for a total cumulative survival rate of 97.8% at the implant level. Mean marginal bone loss was 0.90 ± 0.78 mm. Most sites (70%) had a crown-to-implant ratio ≥1 (mean = 1.16 ± 0.36). Correlation analyses revealed that sites with crown-to-implant ratio <1 presented greater marginal bone loss (1.14 ± 0.75 mm) compared to ratios of 1–1.99 and ≥2 (0.81 ± 0.77 mm and 0.45 ± 0.47 mm, respectively). However, these findings should be interpreted with caution due to the retrospective nature of the study. It was also observed that peri-implant marginal bone loss and complication rates were not statistically different between splinted and non-splinted prostheses.[85]

Another retrospective study evaluated the performance of short implants (<8 mm) in posterior maxillary and mandibular partially edentulous regions. Data were retrieved from the health records of 148 patients who were treated with a total of 225 short implants between 2005 and 2014 after an observational period of up to 14 years in clinical function. Outcomes such as implant stability, marginal bone loss, and success/survival rates were assessed. The results of this comprehensive retrospective study revealed an overall success and survival rate of 93.33% and 97.78%, respectively. Cumulative 5- and 10-year survival rates were 99.05% and 96.72%, respectively. Average marginal bone loss was 0.43 mm.[86]

		Combinations				
PLGA+BCP (Easy graft crystal®)[195]	Bioglass (NovaBone®)[196]	Bovine xenograft (Bio-Oss®) + AB 50:50 ratio[197]	Bovine xenograft (Bio-Oss®) + AB 80:20 ratio[197]	Corticocancellous allograft particles (MinerOss®) + AB 50:50 ratio[198]	Porcine xenograft (Symbios®) + AB 80:20 ratio[199]	Algae-TCP (Symbios®) + AB 80:20 ratio[200]
31.25%	33.08%	36%	37.38%	41.03%	32.51%	24.14%
46.0%	53.35%	44.8%	31.92%	49.00%	36.28%	65.87%
23.38%	14.15%	19.36%	30.75%	9.83%	31.21%	7.96%
34.29	N/A	160.11	75.27	36.38	51.93	19.35
107.97	N/A	631.85	219.08	139.38	113.87	185.48
7.46	N/A	106.38	50.41	2.99	55.55	3.22
138	N/A	N/A	N/A	169.11	163.86	236.90
N/A	N/A	18.05	9.01	5.14	2.50	N/A
27	N/A	N/A	N/A	52.06	23.30	35.48

Summative high-level evidence in the form of systematic reviews and meta-analyses is also quite revealing. A Cochrane systematic review and meta-analysis published in 2014 identified four clinical trials that evaluated short implants (5- to 8.5-mm long) as an alternative to maxillary sinus floor augmentation in sites presenting a residual bone height between 4 and 9 mm. One year after loading there was insufficient evidence to claim differences between the two procedures in terms of prosthetic (OR = 0.37) or implant failure (OR = 0.44). Nonetheless, a higher risk of complications (e.g., infection, hemorrhage, nerve injury, etc.) was observed at sites that underwent maxillary sinus floor augmentation (OR = 4.77).[87]

As part of the 2015 European Association for Osseointegration (EAO) consensus conference, a systematic review was conducted on the performance of short dental implants (≤8 mm) in comparison to maxillary sinus floor augmentation surgery and conventional implant placement.[88] A total of 8 randomized controlled trials that were published between 1990 and 2014 were selected. Overall, results demonstrated that short implants achieved survival rates comparable to standard-length implants placed in conjunction with maxillary sinus augmentation surgery (98.0%–99.2% for short implants vs. 99.5%–99.0% for standard-length implants). However, the incidence of complications was higher, at a three-fold rate, for maxillary sinus floor augmentation (mainly Schneiderian membrane tears), leading to extended morbidity and recovery periods, and increased financial expenses.[88]

A systematic review conducted in the context of the 6th International Team for Implantology (ITI) consensus conference included 10 randomized controlled trials comparing long (>6 mm) and short (≤6 mm) dental implants placed in posterior edentulous regions. The sample was constituted by data from 637 short dental implants and 653 standard-length implants placed in 775 patients. It was found that, in terms of survival rate, short implants are associated with higher variability and lower predictability compared to longer implants after periods of 1–5 years in function. Nevertheless, the reported mean survival rate was high, at 96% (range: 86.7%–100%) for short implants and 98% (range: 95%–100%) for longer implants.[89]

Regarding extra-short implants (≤6 mm), a systematic review and meta-analysis involving a total of 24 selected clinical trials including 657 implants with a maximum follow-up of 5 years revealed that single crowns supported by extra-short implants exhibited a similar risk of failure to those supported by conventional implants, independently of history of maxillary sinus floor augmentation, for a cumulative failure rate of 5.19%. Interestingly, biological complications were more frequent than biomechanical/prosthetic complications.[90]

In summary, a strong body of clinical evidence generally supports the efficacy of short dental implants as a viable treatment alternative to major bone augmentation and placement of standard-length implants for the rehabilitation of posterior edentulous segments.[91–94] Cost-effectiveness, lower invasiveness and morbidity, and patient preferences (e.g., shorter treatment time) are additional factors that should be taken into consideration when making clinical decisions on the use of short dental implants. Clinical guidelines for case selection, treatment planning, surgical placement, prosthetic rehabilitation, risk assessment, and maintenance of short dental implants are essentially the same as those recommended for conventional implants,[95] with additional careful consideration of specific prosthetic

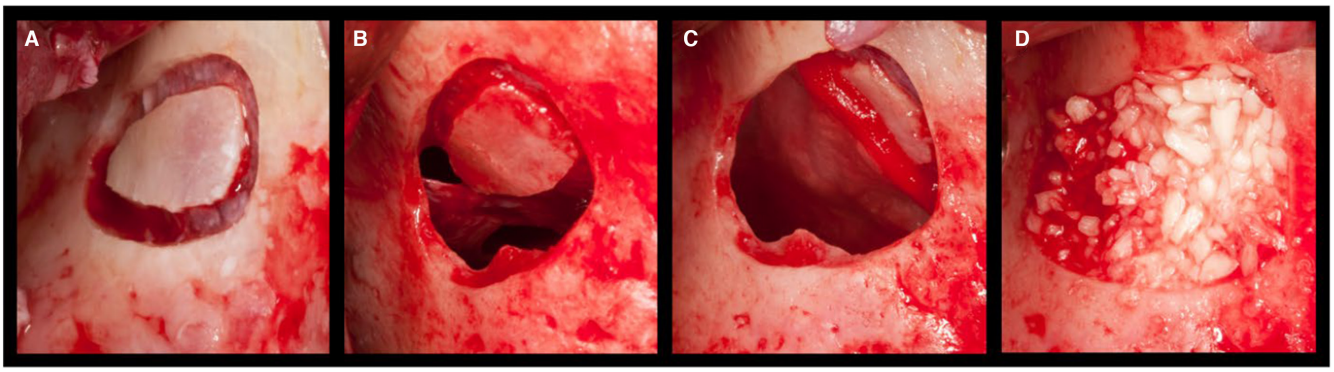

FIGURE 8 Lateral window outlined after using a piezosurgery instrument (A). Two separate perforations occurred upon Schneiderian membrane elevation because the membrane was very thin in some areas (B). An absorbable porcine collagen membrane was trimmed and carefully applied to seal the perforations (C). Once the perforations were sealed, a particulate cortical allograft material was safely used to augment the maxillary sinus floor (D). (Adapted with permission from Avila-Ortiz et al.[1]).

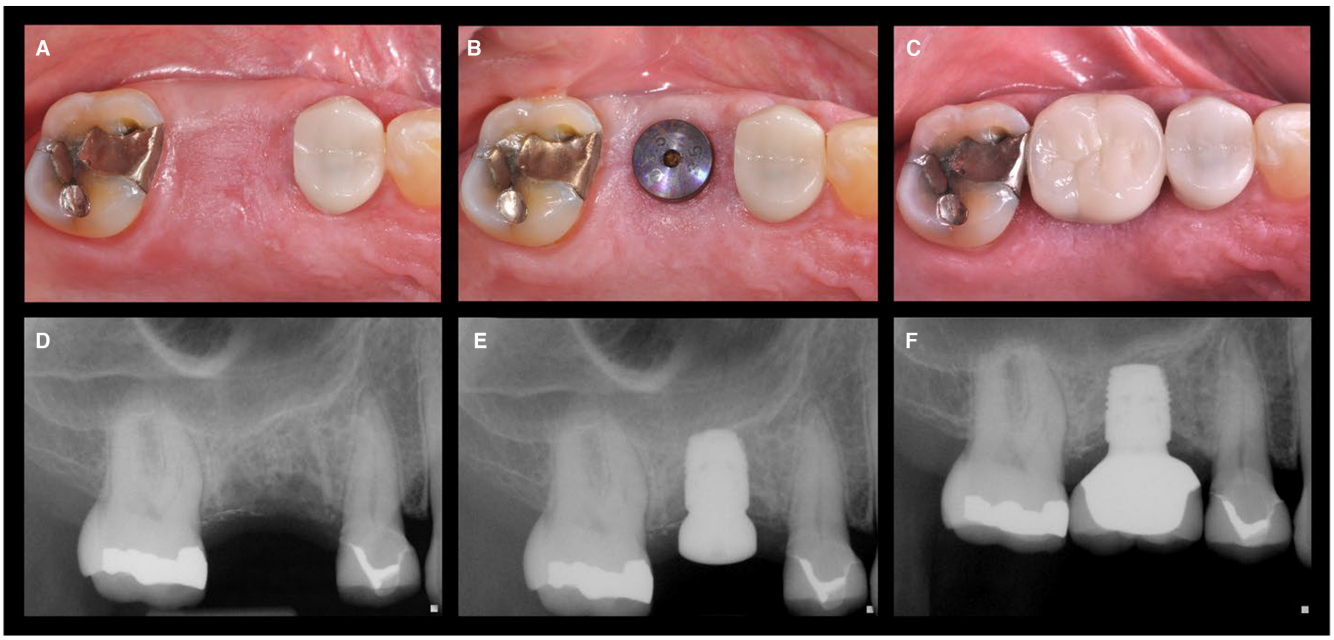

FIGURE 9 Sequence of a case of tooth replacement therapy of a maxillary right first molar with an implant-supported fixed dental prosthesis involving the use of a short implant to avoid maxillary sinus floor augmentation. The upper row shows the intraoral aspect of the site at baseline (A), 2 months after implant placement (B), and 1 year after the delivery of the final prosthesis (C). The lower row displays a periapical radiographic sequence of the area at baseline (D), 2 months after implant placement (E), and 1 year after the delivery of the final prosthesis (F). (Adapted with permission from Avila-Ortiz et al.[1]).

aspects, such as crown-to-implant ratio and use of cantilever extensions, due to biomechanical concerns, particularly in sites with significant vertical bone atrophy and large interocclusal space.[96]

2.3 | Tilted implants

Like short dental implants, tilted implants offer the advantage of minimizing or completely avoiding the indication of ancillary bone augmentation procedures, which may potentially reduce morbidity, total treatment time, and expenses. Tilted implants are intentionally placed in a non-axial mesial or distal direction in areas where sufficient native bone is available to avoid damaging or invading important anatomical structures (e.g., maxillary sinus cavity), to reduce or eliminate the need for bone augmentation, to decrease the extent of or avoid a prosthetic cantilever extension, and/or to allow the placement of longer implants with increased bone-to-implant contact. Other terms analogous to tilted implants that can be found in the literature are "angled implants" or "angulated implants."

Stemming from the concept of tilted pterygomaxillary implants originally described in the 1990s,[97,98] the placement of tilted dental implants within the alveolar arch was originally described by Krekmanov and colleagues in 2000 as a novel therapeutic approach to rehabilitate completely edentulous maxillary and mandibular arches in a minimally invasive way. These authors described the insertion of implants tilted in a mesial or distal direction, mainly within

the existing alveolar bone, thereby reducing the need for extensive bone augmentation and shortening the length of prosthetic cantilevers, while still allowing for the replacement of an optimal number of masticatory units.[99] A secondary benefit of tilted implants can be to reduce the number of implants required to support the dental prosthesis. Maló and coworkers described in 2003 an approach that consisted of the combination of upright and tilted implants with immediate implant loading for the rehabilitation of fully edentulous arches.[100] In this protocol, known as the "All-on-4" concept, four implants are spread along the arch, two in the anterior part of the maxilla with no intentional axial deviation, and two in the premolar or first molar position, with a variable mesial angulation (typically 35–40°), to avoid maxillary sinus floor augmentation and/or extensive reconstruction of the alveolar ridge.[101] Depending on the anatomical characteristics of the maxilla, placement of implants that partially invade the maxillary sinus cavity may be inevitable in the context of this protocol,[102] which may increase the incidence of complications. Also, this approach often involves the implementation of distal cantilevers, a prosthetic option that will be addressed in the next section of this review. The clinical validity of this treatment concept for the rehabilitation of the atrophic fully edentulous maxilla has been supported by independent investigations.[103–106] However, the failure of just one of the four fixtures, particularly either of the tilted ones, usually represents a major setback, as in many instances the whole prosthetic structure cannot be biomechanically supported by the remaining implants in the long term predictably. It is important to keep in mind that excessive cantilever length can lead to deleterious strain on the implants and prosthetic components, which may increase the risk of biological and biomechanical complications.[107,108] With the purpose of addressing the potential limitations of the "All-on-4" protocol, other similar treatment approaches based on the use of a higher number of implants (e.g., six or eight) have been proposed, with similar therapeutic success.[109–111] Some of these advanced protocols involve the placement of long, tilted implants that are anchored in the pterygoid or zygomatic region (Figure 10).[112,113]

Pterygoid implants, also known as pterygomaxillary or tuberosity implants, are inserted in the retromolar region of the partially or, more frequently, the completely edentulous maxilla mainly to avoid bone augmentation procedures and distal cantilevers. The placement of pterygoid implants to support full-arch prostheses was originally introduced by Tulasne in 1992.[114] Although there is no consensus as to whether drills, osteotomes, or both should be used during the surgical intervention, the authors of a retrospective study that reported the clinical outcomes of 68 pterygoid implants placed in 45 patients recommended the combination of drills for initial osteotomy and osteotomes to finalize the implant site preparation to preserve and densify the bone and minimize surgical risk.[115] Regardless of the method of osteotomy preparation, an important requirement for the placement of pterygoid implants is a minimum mouth opening of approximately 35 mm in order to adequately execute the surgical procedure, which in some cases may be a limiting factor. Two systematic reviews available on this topic reported relatively high survival rates up to approximately 10 years for pterygoid implants, ranging from 90.9% to 94.8%.[112,116] However, all of the selected studies were retrospective in nature and generally exhibited a high risk of bias. Additionally, data on biological and prosthetic complications and the effect of different confounding factors (e.g., age, gender, implant manufacturer, type of prosthesis, implant surface, and smoking habits) on the outcomes of therapy is scarce, which prevents drawing conclusions pertaining to the clinical performance of this treatment option and highlights the need for high-level clinical research to be conducted in this field.

Zygomatic implants are another alternative for the rehabilitation of the atrophic maxilla either with a delayed or an immediate loading protocol. Aparicio and collaborators first proposed in 1993 the insertion of long machined surface implants anchored in the zygomatic bone for the rehabilitation of an edentulous premaxilla.[117] Installation of implants anchored in the zygomatic bone frequently involves the invasion of the maxillary sinus cavity, in a subcategory known as "trans-sinus" implants. Important downsides of zygomatic implants are the lack of clear surgical visualization, longer surgical time if the sinus membrane is lifted and not deliberately perforated, the risk for adverse events related to maxillary sinus surgery (e.g., damage to vascular structures or sinusitis), unfavorable emergence profile and reduced anchorage in the zygomatic bone, depending on anatomical and structural features. In general, systematic reviews on

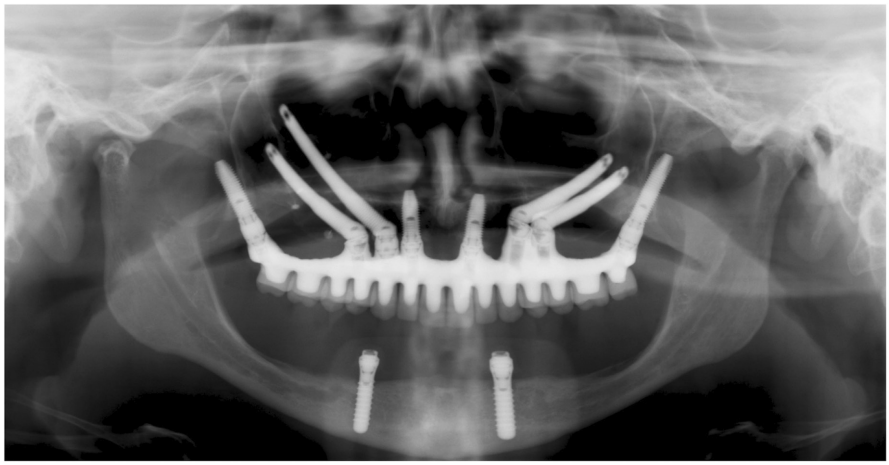

FIGURE 10 Orthopantomograph showing the combined use of zygomatic and pterygoid implants to support a full-arch implant-supported fixed dental prosthesis. (Adapted with permission from Avila-Ortiz et al.[1]).

this topic have reported high survival rates for zygomatic implants supporting full-arch rehabilitations.[118–123] For example, Chrcanovic and collaborators analyzed the data extracted from 68 studies that reported the outcomes of 4556 zygomatic implants placed in 2161 patients. The 12-year cumulative implant survival rate was 95.2%. Interestingly, most failures occurred within 6 months after implant placement. Twenty-six of the 68 studies exclusively evaluated the results after immediate implant loading for full-arch rehabilitation showing a high implant survival rate of 98.3%. The authors estimated the probability of postoperative complications, including sinusitis (2.4%), peri-implant mucosa infection [possibly peri-implantitis] (2.0%), paresthesia of infraorbital or zygomaticofacialis nerve (1.0%), and oroantral fistulas (0.4%).[119] However, these findings should be interpreted with caution as the incidence of adverse events, both biological and prosthetic, might be underestimated due to under-reporting of postoperative complications in the selected studies, which appears to be a consistent observation in similar systematic reviews.[118,121,123]

Trans-sinus implants, also knowns as trans-sinusal implants, are another modality of tilted implants that can be utilized in some cases as a less invasive alternative compared to zygomatic and pterygoid implants. Trans-sinus implants are typically placed in the anterior aspect of the maxillary sinus cavity with a variable degree of mesial tilt and are fixated to the lateral nasal wall, as originally described by Jensen and colleagues.[124] The installation of trans-sinus implants can be combined with simultaneous bone augmentation, with limited elevation of the Schneiderian membrane, or placed with a graftless approach.[125] Although it is important to remark that the number of publications on the use of trans-sinus is very limited and the level of evidence of these reports is generally low, this treatment seems to be associated with satisfactory outcomes and, therefore, could be considered as a feasible alternative in clinical practice.[102,126–129]

While tilted pterygoid, zygomatic, and trans-sinus implants are valid treatment options for the rehabilitation of the posterior maxilla, it must be remarked that scrupulous case selection and a refined surgical technique are crucial to prevent the occurrence of severe complications (e.g., nasal mucosa damage, orbital floor perforation, zygomatic bone fracture, nerve damage, or sinusitis) due to incorrect osteotomy preparation and implant positioning.[130,131]

In the context of this scoping review, when interpreting the evidence pertaining to the performance of tilted implants, it is important to highlight that the vast majority of available studies on the topic are focused on full-arch prosthetic rehabilitations, often delivered immediately after implant placement, and very few on the treatment of partial edentulism in the posterior maxilla.[126,132] Additionally, most studies are retrospective in nature and only a few proper randomized clinical trials are available to determine the efficacy of this modality of treatment. In this regard, it is worth highlighting a systematic review prepared for the 5th European Association for Osseointegration (EAO) consensus conference that included 17 studies, 4 and 13 reporting on the outcomes of partial and full-arch fixed dental prostheses supported by tilted implants, respectively, not including zygomatic and trans-sinus implants.[133] The authors of this review published in 2018 could not identify any eligible randomized clinical trials and almost half of the included studies were prospective ($n = 8$; 47%), while the rest were retrospective ($n = 9$; 53%). Notably, most selected studies (87%) exhibited a high risk of bias. The sample was constituted by 7568 implants placed in 1849 patients. The follow-up time ranged between 3 and 10 years. It was concluded that there is no compelling evidence indicating that implant failure and marginal bone loss is higher for tilted implants compared to straight implants.[133] In the consensus report, Hämmerle et al.[134] further stated that whether tilted implants have a negative impact on peri-implant soft tissues or predispose the occurrence of prosthetic complications cannot be determined on the basis of available evidence. Thus, more studies are needed to determine whether tilted implants may provide a long-standing alternative to upright implants when patient-related variables (e.g., medical history or anatomical limitations) or other factors preclude the indication of advanced bone grafting, such as maxillary sinus floor augmentation.

2.4 | Distal cantilevers

When restoring missing teeth in the posterior maxilla, it is crucial to determine how far posteriorly the edentulous area needs to be restored. Do we need to restore the missing teeth back to the second molar or is it sufficient to restore the occlusal units back to the first molar or can it be enough to restore only the premolar units to provide the patient with an adequate occlusion?

Several factors can influence the treatment plan, such as the occlusal scheme and restorative status of the opposing jaw, the smile, the size of the buccal corridor, and the number of occlusion units required. Kayser and co-workers extensively investigated the chewing capacity of patients with reduced or compromised occlusion, particularly in the elderly population.[135–140] In relation to the size of the occlusal surface, premolars were considered as one chewing unit and molars accounted for two chewing units. It was concluded that individuals that are missing the second molars, having four chewing units (i.e., two premolars and one molar) instead of six, do not exhibit a significant reduction in their chewing capacity. Interestingly, they also reported that individuals that have lost both molars, having only premolars (or two chewing units), still have approximately 80% of the maximum chewing capacity.[19] Hence, restoring the posterior area in the maxilla with one premolar and one molar is certainly an option to provide patients with sufficient chewing capacity.[141]

As an additional prosthetic resource, cantilever units can be employed in the posterior maxilla to extend implant- or tooth-supported fixed dental prostheses in a mesial or, more frequently, a distal direction and give patients additional chewing units, while avoiding the need for implant placement and ancillary bone augmentation. Like short and tilted implants, this approach can reduce morbidity, cost, and total treatment time compared to maxillary sinus floor augmentation and placement of standard dental implants. The use of distal cantilever units in the posterior maxilla was initially introduced in

the field of implant dentistry as treatment modality for totally edentulous patients in need of full-arch implant-supported fixed dental prostheses. The use of implant-supported distal cantilevers has shown excellent long-term outcomes for totally edentulous patients, as well as for the rehabilitation of short edentulous spans with two to four implants supporting one distal cantilever unit.[142,143] Some authors even recommend single implants supporting a crown with an extension unit. This treatment modality has become quite popular and studies on different cohorts have revealed that between 7% and 67% of all multi-unit implant-supported fixed dental prostheses inserted have extension units.[144–148]

Even though there is a limited number of clinical studies available that have investigated in detail the clinical outcomes of implant-supported fixed dental prostheses with a cantilever, eight systematic reviews including three to nine studies each have been published on the topic to date.[149–156] All these systematic reviews coincide in that implant-supported fixed dental prostheses with a cantilever represent a valid and reliable treatment option both for partially and completely edentulous patients. Aglietta and co-workers included the data from five studies reporting on 180 implant-supported cantilever fixed dental prostheses supported by 420 dental implants in their meta-analysis.[149] The estimated annual failure rate of 1.18% was similar to the annual failure rate of 1.03% reported in a meta-analysis by Pjetursson and co-workers on conventional non-cantilever implant-supported fixed dental prostheses.[157] Furthermore, based on the evidence reported in the aforementioned systematic reviews, it appears that the incidence of biological complications is similar to the values that have been reported for conventional implant-supported fixed dental prostheses.

A systematic review on this topic published in 2018 included studies that compared the outcomes of implant-supported cantilever fixed dental prostheses to conventional non-cantilever implant-supported fixed dental prostheses.[155] Four studies[158–161] could be included and three meta-analyses were performed. Regarding the survival rate of the supporting implant, the estimated risk ratio was 3.91, favoring conventional non-cantilever fixed dental prostheses. Even though the risk ratio did not reach statistical significance ($p = 0.07$), there may be a tendency for higher implant failure rates in association with cantilever-fixed dental prostheses. The same was observed for marginal bone loss evaluated on radiographs with a mean difference of 0.12 mm favoring conventional non-cantilever implants. The third meta-analysis addressed complications affecting the supporting implants. More complications were detected for the implant-supported fixed dental prostheses with cantilever compared to prosthetic restorations with no cantilever for a risk ratio of 2.56, which was associated with statistical significance ($p = 0.008$). This finding is in alignment with most of the studies on implant-supported cantilever fixed dental prostheses, which have reported higher incidence of prosthetic complications, such as ceramic fractures and chipping, loss of retention, fixation screw loosening, and implant fracture. The authors of this systematic review concluded that the incidence of complications was related to the length of the cantilever unit.[159] However, it must be kept in mind that, in the included studies the length of the cantilever united ranged from 7 to 9 mm, which represents a premolar or a small molar. Hence, the findings of these studies cannot be extrapolated to implant-supported fixed dental prostheses with longer cantilever units, or shorter cantilevers in anterior areas.

Furthermore, the evidence available for the use of implant-supported cantilever fixed dental prostheses is almost exclusively based on restorations with a metal framework and not a ceramic framework, which has become more popular in implant dentistry. When ceramic is used as the framework material for cantilever restorations, the design of the framework is of paramount importance. Unveneered shoulders should be employed and the connector area should be maximized by reducing the size of the embrasures.[162] Additionally, monolithic or micro-veneered restorations utilizing high-strength zirconia are preferred. If a titanium base concept is used for the fabrication of implant-supported cantilever fixed dental prostheses to allow full utilization of the digital workflow, a monolithic restoration can be designed, milled, and adhesively cemented to the titanium base abutment extra-orally, and then directly screw-retained to the implant as a conventional one-piece, screw-retained restoration.[163] Notwithstanding all advantages of the titanium-base abutment concept, its success is highly dependent on the bonding stability between the titanium base and the overlying ceramic components. With the purpose of achieving a high and durable adhesive retention, several surface pre-treatments have been proposed. Considering the outcomes of several studies, sandblasting of the titanium base abutments with 50-μm Al_2O_3 is generally recommended.[164] Besides the preconditioning of the titanium base abutment, the selection of the resin cement also plays a crucial role in the clinical success of restorations designed according to the titanium-base abutment concept.[165]

Although the use of a single implant with a cantilever or extension unit has widely spread in recent years, most of the evidence related to this treatment modality is based on data obtained from anterior sites.[166] Hence, it is important to remark that there is still limited evidence supporting this treatment modality in the posterior maxilla[158–160,167] and most of the restorations that have been evaluated in longitudinal studies are single implants supporting a premolar size crown with a premolar size extension. This type of reconstruction offers a total occlusal surface of approximately 14 mm, which is slightly larger than the standard occlusal surface of approximately 12 mm that is typically provided by an implant-supported molar.

When implant-supported cantilever fixed dental prostheses are used to restore missing teeth in the posterior maxilla, the same meticulous occlusal analysis and planning recommended for tooth-supported cantilever fixed dental prostheses should be followed.[168,169] The cantilever unit should only be in contact in the maximum intercuspal position on flat and not oblique surfaces, and be out of contact in all excursive positions.[170] It is generally recommended to leave the cantilever unit slightly out of occlusion when it opposes an implant-supported restoration, but to have it in contact in maximum intercuspation when it is occluding against a natural tooth or a tooth-supported restoration.

3 | CLINICAL DECISION-MAKING

Clinical decision-making should be guided by a comprehensive, balanced, and hierarchical assessment and interpretation of relevant evidence and the evaluation of relevant local and systemic variables, leveraging a comprehensive diagnostic process based on a meticulous clinical and radiographic exam using advanced imaging (e.g., cone-beam computed tomography) to rigorously appraise different treatment options and ultimately draw truthful and plausible conclusions that may be broadly and predictably applied in practice.[171–173] While maxillary sinus floor augmentation and standard-length implant placement has been widely regarded as the primary option for the rehabilitation of the posterior edentulous maxilla using implant-supported fixed dental prostheses when insufficient bone is available, based on the information previously presented in this review, it is evident that other therapeutic options can and should be pondered as viable alternatives.

There are several therapeutic options that may be considered, as follows:

- Standard implants
- Transalveolar maxillary sinus floor augmentation with simultaneous implant placement
- Maxillary sinus floor augmentation via lateral window with simultaneous or delayed implant placement
- Short implants
- Tilted implants
- Distal cantilevers

An overview of the main indications, advantages and disadvantages of these different therapeutic options is displayed in Table 2.

While there are numerous local and systemic factors that should be accounted for in the process of treatment planning, the height of the subantral bony ridge, which is commonly referred to as "residual bone height," is arguably the main driver in the planning and execution of implant therapy in the posterior maxilla. Although baseline remaining bone height per se does not seem to play a critical role in implant integration[174] or new bone formation after maxillary sinus floor augmentation,[175] this anatomical variable is used to assess the proximity of the sinus floor to alveolar ridge crest and, therefore, determine the need for maxillary sinus floor augmentation. It also has a direct influence on the probability of achieving implant primary stability.

Departing from the assumption that there are no medical contraindications for intraoral surgery, that no severe alveolar ridge defects that would require major horizontal and/or vertical bone augmentation are present, that there is a favorable interocclusal distance, that the type of edentulism and tooth anatomy allows for the placement of tilted implants without damaging adjacent dental structures, and that the plan involves restoration of at least first molar occlusion, the following guidelines, based on the information presented in this review and other general recommendations published elsewhere,[1] are hereby proposed (Figure 11):

- Remaining bone height > 9 mm: Standard implant (length ≥ 8 mm) or short implant (length < 8 mm) placement, projecting that a minimum of 1 mm of bone height apical to the implant fixture will be left intact.
- Remaining bone height of >5 to ≤9 mm: transalveolar maxillary sinus floor augmentation and simultaneous standard implant placement or short implant placement with no bone augmentation.

TABLE 2 Therapeutic options for the rehabilitation of the posterior edentulous maxilla with implant-supported fixed dental prostheses.

Therapeutic options	Main indications	Main advantages	Main disadvantages
Standard implant(s)	Edentulous sites with subantral RBH >9 mm	Reduces or eliminates the need for bone augmentation	Nothing remarkable compared to the other options below
Transalveolar MSFA with simultaneous implant placement	Edentulous sites with subantral RBH >5 to ≤9 mm	Less invasive than MSFA via lateral window	• Limited visibility compared to MSFA via lateral window approach • May cause benign paroxysmal positional vertigo if osteotomes are used
MSFA via lateral window with simultaneous implant placement	Edentulous sites with subantral RBH >3 to ≤5 mm	Increased visibility compared to MSFA via lateral window	• More invasive and technically demanding than transcrestal MSFA • Higher rate of severe complications compared to other options
MSFA via lateral window with delayed implant placement	Edentulous sites with subantral RBH ≤3 mm		
Short implant(s)	Edentulous sites with subantral RBH >5 to ≥9 mm	Reduces or eliminates the need for bone augmentation	Potential prosthetic complications if crown-to-implant ratio is not favorable
Tilted implant(s)	Edentulous sites with subantral RBH ≤5 mm	Reduces or eliminates the need for bone augmentation	Limited evidence on long-term biological and prosthetic complications
Distal cantilever	Edentulous with subantral RBH ≤5 mm	No need for bone augmentation	Potential prosthetic complications if not properly designed

Abbreviations: MSFA, Maxillary sinus floor augmentation; RBH, Remaining bone height.

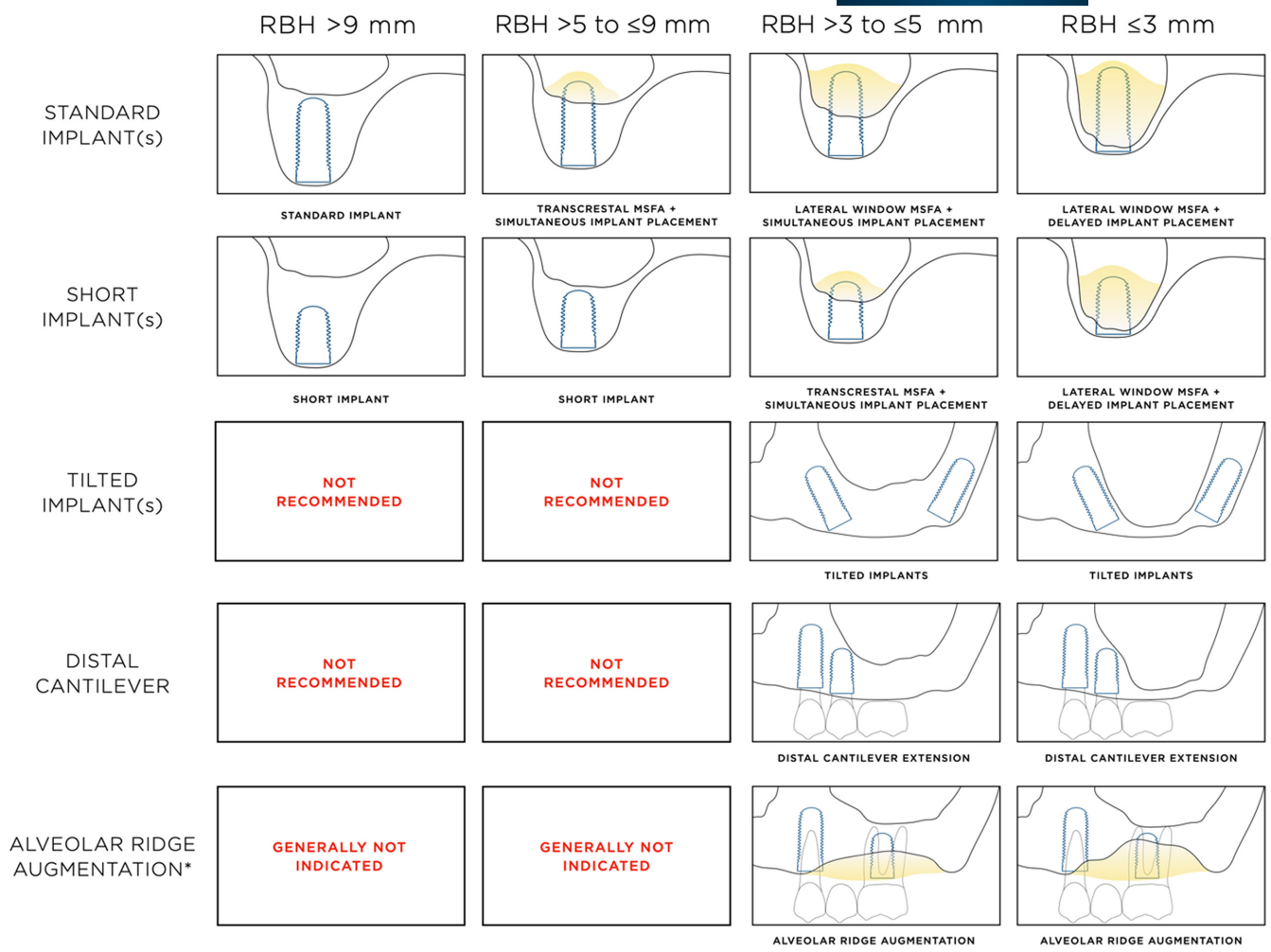

FIGURE 11 Treatment options for the rehabilitation of the posterior edentulous maxilla with implant-supported fixed dental prostheses as a function of the remaining bone height. *It must be remarked that alveolar ridge augmentation is particularly indicated in areas exhibiting very limited remaining bone height and a negative osseous architecture. MSFA, Maxillary sinus floor augmentation; RBH, Remaining bone height.

- Remaining bone height of >3 to ≤5 mm: Maxillary sinus floor augmentation with a lateral window approach and simultaneous implant placement, or transalveolar maxillary sinus floor augmentation and simultaneous short implant placement, or tilted implant(s), or distal cantilever extension.
- Remaining bone height ≤ 3 mm: Maxillary sinus floor augmentation with a lateral window approach and delayed standard or short implant placement, or tilted implant(s), or distal cantilever extension.
- Although more technique-sensitive and invasive, another viable option for the management of the edentulous posterior maxilla, which is particularly indicated in situations of limited subantral bone height when there is a negative alveolar ridge architecture is alveolar ridge augmentation.[176]

Other possible alternatives that may be considered for the rehabilitation of extremely atrophic posterior maxillary segments are LeFort I osteotomies and interpositional bone grafts with or without simultaneous maxillary sinus floor augmentation[177,178] or superiosteal implants[179,180]; however, these treatments are not routinely performed in most clinical settings mainly because of their technical complexity and patient preferences.

Clinicians should keep in mind that, as a general therapeutic principle, the most predictable, less invasive, and less time-consuming modality of treatment should be prioritized after careful consideration of relevant local and systemic factors. For example, in a site that exhibits 7 mm of residual bone height, between transalveolar maxillary sinus floor augmentation with simultaneous standard implant placement and a short implant with no grafting, being both predictable approaches according to current scientific evidence, the latter represents the least invasive and more time-efficient option.

It must be noted that even if an alternative to maxillary sinus floor augmentation is selected, the need for bone augmentation at the time of implant placement may not be eliminated, particularly in ridges with limited horizontal bone availability where the occurrence of peri-implant dehiscences is likely. A possible strategy to prevent these situations is to employ dental implants of a reduced diameter if biomechanical ramifications have been carefully considered.

Finally, as mentioned elsewhere,[1] it is important to remark that numeric thresholds and therapeutic recommendations should always be interpreted with caution prior to making treatment planning decisions. These should be based upon multiple factors including the skill and preferences of the surgeon, the characteristics of the implant system employed, the planned contour of the final prosthetic restoration relative to the location of the implant restorative platform, the presence of concomitant pathosis,[181,182] and additional anatomic variables that may play a role in the execution of the technique, such as configuration of the sinus floor,[183,184] presence and morphology of septa,[185] mediolateral sinus width,[186,187] thickness of the lateral sinus wall,[188] size and location of the posterior superior alveolar artery,[189] and thickness of the Schneiderian membrane,[190,191] among other variables. In the planning stage, it is also crucial to account for individual patient preferences filtered through a critical appraisal of patient-reported outcome measures (PROMs) reported in the scientific literature.

4 | CONCLUSIONS

Maxillary sinus floor augmentation either with delayed or simultaneous implant placement, short dental implants, tilted implants, and distal cantilever extensions are viable therapeutic options for the rehabilitation of posterior edentulous maxillary segments with implant-supported fixed dental prostheses. However, a meticulous assessment of patient-related local and systemic factors, with an emphasis on the subantral remaining bone height, as well as a careful consideration of patient preferences, surgical, and prosthetic factors are fundamental to achieve a satisfactory, long-term outcome.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to report pertaining to the conduction of this review.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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