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REVIEW ARTICLE

Is alveolar ridge preservation an overtreatment?

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1 | INTRODUCTION

Following tooth extraction, a well-described healing process takes place, to achieve wound closure and re-establishment of homeostasis.[1,2] Postextraction healing comprises a sequence of biologic events including the formation and resorption of the blood clot, inflammation, migration, proliferation and differentiation of various cell populations, connective tissue matrix production and mineralization, and finally modeling and remodeling of the newly formed tissues.[1,3] This sequence of events is conducted by an interplay of various cytokines, chemokines, and growth factors, that directs cellular recruitment via the activation of signaling pathways similar to that found in other examples of intramenbranous osseous healing.[4] During the osseous healing, the walls of the socket will undergo significant three-dimensional resorption, resulting in morphological and topographical changes in hard and soft tissues and alteration to the contour of the pre-extraction alveolar process.[5] The extent of the bone and soft tissue dimensional change is influenced by several systemic and local or anatomic factors. Therefore, the amount of new bone formation within the extraction socket and the extent of volumetric reduction in the alveolar ridge cannot be easily predicted and may vary not only between individuals but also between different extraction sockets in the same patient.[6–8]

With the current shift toward prosthetically driven implant placement protocols, the morphology and dimensions of the postextraction alveolar ridge are important for both the surgical and restorative stages of implant treatment.[9,10] Adequate new bone formation and preservation of the pre-extraction alveolar bone dimensions will facilitate the installation of the implant fixture in an ideal restorative position. In addition, retention of the pre-extraction soft tissue contour and volume is considered essential for the provision of an aesthetic implant-supported restoration with healthy peri-implant tissues.[11,12] Moreover, it is not uncommon that only a limited amount of bone is available after tooth extraction. This bone deficiency may complicate the provision of implant-supported restorations[13,14] and, at the same time, may increase the risk of early and late implant complications or aesthetic failures.[15,16] Previous systematic reviews and meta-analyses[6,8,17] have concluded that postextraction resorption results into significant changes in the alveolar ridge dimensions regardless but depended on tooth type. The risks associated with this dimensional change are particularly evident in the anterior zone, due to the presence of the thin bundle bone[1] that may predispose to severe alveolar resorption.[18] Augmentation surgical protocols have therefore been developed to reconstruct the original bone and soft tissue contour at different stages of implant treatment.[19–21] Although the development of bone and soft tissue augmentation techniques has improved their predictability, even in highly resorbed alveolar ridges, their application is technically challenging and may not be compatible with the training and expertise of the average dental practitioner.[16,22] Furthermore, staged reconstruction of large alveolar bone defects can often involve extended intraoral or extraoral bone grafting, that may be associated with a significant increase in morbidity and treatment cost for the patient.[14]

The term alveolar ridge preservation (ARP) refers to any procedure developed to eliminate or limit the postextraction resorption of the alveolar ridge and promote bone formation within the socket[23,24] Ideally, the goals of any ARP procedure should be: (i) the limitation of postextraction alveolar ridge dimensional changes, for the facilitation of implant placement without the use of additional, extensive bone and soft tissue augmentation procedures and for the optimization of alveolar ridge contour in pontic areas when planning a tooth-supported procedure[9,25]; (ii) the promotion of new bone formation within the healing socket at a compatible level for the osseointegration of a dental implant; and (iii) the promotion of soft tissue healing at the entrance to the alveolar socket and the preservation of the external alveolar ridge contour.

ARP techniques usually involve the placement of a bone graft material within the socket, which can be further combined with a barrier membrane, or a soft tissue graft for sealing the entrance of the socket. The most commonly used ARP techniques can broadly be divided into two categories[9,26–28]: (1) socket grafts—using particulate bone grafts or bone substitutes alone, or in combination with growth factors, biologics, and platelet derivatives and (2) socket sealing (SS)—using a barrier membrane for guided bone regeneration (GBR) or a soft tissue graft (autogenous or exogenous) to seal the entrance of the socket in combination or not with a bone graft or substitute, following a primary or secondary intention healing concept.

Besides the large number of systematic reviews and consensus papers that have confirmed the effectiveness of ARP, its indication and effectiveness have been disputed by some practitioners. They have suggested that ARP procedures are more of an "overtreatment," when considering the techniques' ambiguous additional benefit over unassisted socket healing, in several clinical scenarios.[9,29,30] For example, although the current literature supports the use of ARP to maintain alveolar ridge dimensions after tooth extraction, complete preservation of the pre-extraction ridge dimensions does not occur, as a certain amount of bone and soft tissue remodeling will always occur during the healing process. This dimensional change makes it imperative that additional bone and soft tissue augmentation will be required during implant placement.[9,29,30] Moreover, since the extraction socket is a self-healing osseous defect, where bone formation is naturally occurring, the application of ARP can be strongly debated, considering that several biomaterials advocated in ARP procedures have been shown to reduce the actual amount of new bone formation and may delay osseous socket healing.[31,32] Finally, if a dental implant can be placed immediately into a fresh extraction socket (Type 1) or within 6–8 weeks following extraction with or without simultaneous bone regeneration (Type 2), there appears to be little clinical benefit in delaying implant placement by carrying out ARP at the time of extraction.[20,33,34]

The aim of this narrative review is to discuss the evidence pertaining to the key objectives of ARP that have been outlined above and to determine where ARP can lead to favorable outcomes when compared to unassisted socket healing.

2 | POSTEXTRACTION DIMENSIONAL CHANGES IN ALVEOLAR RIDGE

2.1 | Unassisted socket healing—factors that influence bone resorption

The alveolar process is the part of mandible or the maxilla that contains the teeth. The teeth are held in place in an osseous socket or alveoli, which is formed by the fusion of the facial, lingual/palatal, and interdental septum of the alveolar bone. The teeth type, size, anatomy, eruption line, and inclination determine the shape of alveolar process and contribute to the significant socket variability that occurs not only between individuals but also within different sites in the same individual.[35] The alveolar bone proper or "bundle bone" lines the socket and is mainly composed of cortical bone. Bundle bone contains numerous holes where Volkmann canals convey the blood and nerve supply from the alveolar bone into the periodontal ligament (PDL) while at the same time supporting the Sharpey's fibers from the PDL and the cementum.[36] Bundle bone is functionally depended on the PDL and will resorb following tooth extraction, leading to the loss of the Sharpey's fibers and disruption to the associated blood supply from the PDL.[37]

It has been reported that after tooth extraction, the alveolar ridge will undergo significant dimensional changes in both vertical and horizontal directions as a consequence of the bundle bone resorption.[38,39] These changes have been investigated in humans utilizing radiographs,[38,40,41] plaster cast measurements,[42] direct measurements of the ridge following surgical re-entry,[43,44] cone-bean computed tomography (CBCT),[45,46] or combined optical and CBCT images.[47] Systematic reviews have estimated a weighted mean loss of 3.87 mm in width and of 1.67 mm in height[6] or a horizontal bone loss of 29%–63% and vertical bone loss of 11%–22% at 6 months following tooth extraction.[8] The dimensional changes are more pronounced in the horizontal than the vertical plane. The bone dimensional changes are more distinct during the first 6 months of healing,[8] although remodeling continues throughout life, albeit at a slower rate.[48] As a result, the anterior alveolar ridge is shifted more lingually/palatally from its pre-extraction position, resulting in a contour deficit in the labial region.[5,41,42] The differences in the pre- and postextraction buccal and palatal/lingual vertical bone heights have been investigated in several clinical studies, which reported a buccal vertical bone change of −0.9 to −3.6 mm and a palatal vertical change of −0.4 to −3.0 mm after 3–7 months of healing.[44,49,50] This anatomical topographical characteristic is clinically advantageous, as bone and soft augmentation procedures involving the labial aspect of the ridge are easier and more predictable.

The postextraction ridge resorption and remodeling rate vary vastly among patients. It is dependent on several systemic and local factors that play a role in the rate, duration, and extent of bone resorption, ultimately influencing the magnitude of the alveolar ridge volumetric reduction.[51] In addition, the surgical trauma from tooth extraction,[52,53] pre-existing bone loss, or concurrent chronic infection[54,55] may increase and accelerate bone resorption of the surrounding socket walls, while the extraction of single or adjacent multiple teeth may also influence the extent of the vertical and horizontal oral tissue reduction.[10,53,55]

The physiological and metabolic processes involved in wound healing can be adversely affected by systemic conditions such as diabetes,[56] vascular disease, malnutrition,[57] radiation exposure, immunodeficiency, osteoporosis,[58,59] renal disease,[60] endocrine disorders, and smoking.[61] As a result, these conditions may impact postextraction remodeling by reducing and delaying hard and soft tissue healing. Sex, age, and ethnic diversity may also present an increased risk for increased alveolar ridge resorption, as they have been associated with a thinner buccal bone plate in the anterior region.[62,63] The influence of systemic factors on the extent and rate of postextraction alveolar ridge resorption remains largely unknown for either unassisted or assisted socket healing.

The pattern and the extent of socket healing can also be influenced by anatomical differences between individuals, as the location of the extraction site (maxilla or mandible and posterior or anterior regions)[6–8,17,30,41,44,45,50,64–67] and the alveolar process morphology[51] may have an impact too. Differences in the pattern of bone resorption have been reported between the mandible and maxilla,[25,40,45,68] with a tendency for a larger amount of bone loss in the mandible than in the maxilla.[25,68] It remains controversial as to how large these differences are and whether they are clinically significant.[40,45] In a recent systematic review, Couso-Queiruga et al.[17] separately analyzed the postextraction ridge alterations in anterior and posterior teeth, demonstrating that the extraction socket location is related to the extent of dimensional changes; the mean horizontal bone loss in both jaws was 3.61 mm in the posterior region and 2.54 mm in the anterior region. When considering the vertical dimension change, the buccal bone decreased by 1.46 mm in the molar region and 1.65 mm in the anterior region, while less vertical mid-lingual bone loss was observed in the posterior region than in the anterior region (1.20 mm vs. 0.87 mm).[17]

The periodontal phenotype[69,70] is a qualitative combination term that represents both the thickness of the buccal bone plate (bone morphotype), together with the gingival thickness and width of keratinized tissue (gingival phenotype). It has been suggested that the periodontal phenotype has a direct influence on the bone remodeling after tooth extraction[53] and consequently on the functional and aesthetic outcomes of dental implants.[71] In a site with a thick-scalloped phenotype, there is higher chance for preservation of the pre-extraction ridge contour due to the protection offered by the thicker socket wall and gingival tissue, while the thinner bone and gingival thickness associated with a thin-scalloped phenotype may predispose to more pronounced bone resorption and gingival recession. This difference in healing could be attributed to the presence of both lamellar and bundle bone in the socket walls in a patient with a thick periodontal phenotype, which counteracts the tendency for complete bone loss after extraction. The correlation between site-specific dimensional changes in the alveolar ridge after tooth extraction and buccal bone thickness has been shown in numerous clinical studies.[18,67,72–77] Chappuis et al. reported that a thin buccal bone morphotype is a significant risk factor for pronounced vertical bone resorption.[18] Bone resorption at 8 weeks postextraction, in maxillary single-rooted teeth, mainly affected the mid-buccal aspect of the sockets wall, where a mean loss in height of 7.5 mm was recorded, when the thickness of the buccal bone was <1.0 mm (median thickness of 0.7 mm, range, 0.4–1.0 mm). In contrast, a mean loss in height of only 1.1 mm was recorded when the thickness of the socket wall was ≥1.00 mm (median thickness of 1.4 mm, range, 1.1–1.7 mm). The thinner phenotype in the incisor and canine areas also demonstrated more advanced bone resorption, when compared to thicker phenotypes in the premolar areas, suggesting that socket resorption patterns are depending on the periodontal phenotype variation at different extraction site locations.[18] In the anterior maxilla, the buccal bone wall is predominantly thin with <1.0 mm buccal bone thickness. The buccal osseous wall thickness increases at the mid-root level of canine and premolars as well as at the apical level and from the anterior teeth toward the posterior teeth.[10] These specific findings are clinically important considering that in the maxillary anterior region, where aesthetic demands for tooth- or implant-supported restorations are high, the extent of hard and soft tissue loss after extraction due to the thin bone morphotype/thin periodontal phenotype may influence the practitioner's ability to provide a viable, functional, and aesthetic restoration for the extracted tooth (Figure 1A–H).

2.2 | Postextraction dimensional changes in alveolar ridge in assisted socket healing—alveolar ridge preservation

Over the past 20 years, a significant number of clinical studies have demonstrated that ARP protocols using different bone graft materials or substitutes are more efficient in retaining the dimensions of the alveolar ridge than unassisted socket healing, although a certain degree of hard and soft tissue loss will take place and affect the residual ridge morphology.[23,27,43,78–80] Several systematic reviews and meta-analyses[27,30,78,79,81–83] have shown that ARP in comparison with nontreated sites result in a reduction in between 0.79–1.72 mm in height and 0.73–2.96 mm in width of the ridge. The difference between ARP (socket grafting) and unassisted socket healing was 0.16–1.72 mm less reduction in vertical mid-buccal bone height and between 1.61 and 1.99 mm less reduction in horizontal bone width.[27,30] A recent consensus report[28] concluded that ARP via socket grafting may prevent 1.5–2.4 mm of horizontal, 1–2.5 mm of vertical mid-buccal, and 0.8–1.5 mm of mid-lingual vertical bone resorption as compared to tooth extraction alone. Interestingly enough, the systematic review by Macbeth et al. (2016) failed to show a statistically significant different reduction in alveolar ridge width when ARP was compared with unassisted socket healing. This finding contrasted with other recent reviews where the positive effect of ARP was statistically significant for both vertical and horizontal dimensions, albeit the reviews indicated a high variability in the width of alveolar ridge

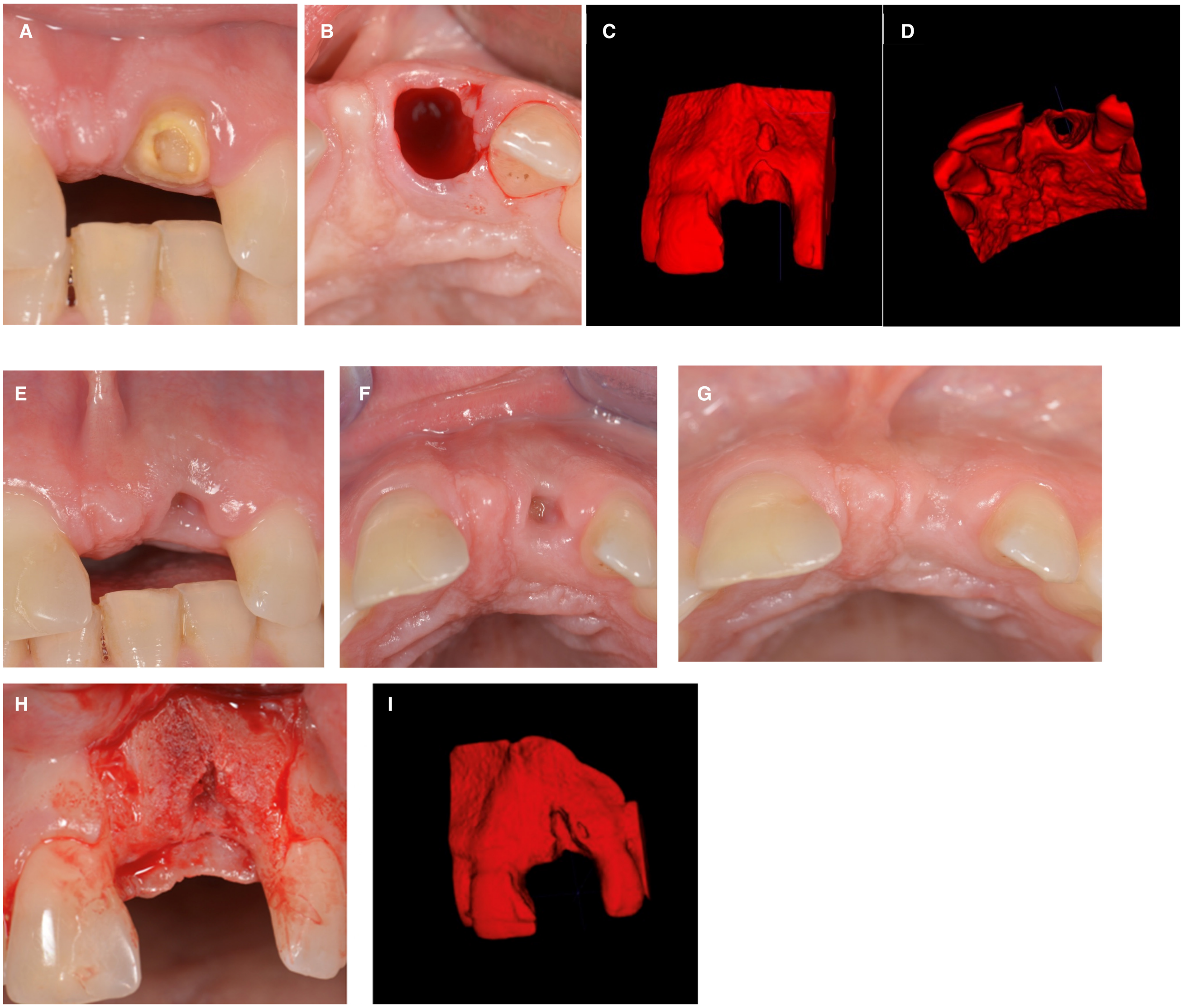

FIGURE 1 Hard and soft tissue dimensional changes after extraction of an upper left central incisor: (A) soft tissue contour prior to root extraction, (B) soft tissue contour immediately after tooth extraction. (C, D) CBCT volume rendering reconstruction showing original socket vertical and horizontal tissue dimensions immediately after tooth extraction, (E, F) vertical and horizontal reduction in soft tissue dimensions at 8 weeks of healing, (G) soft tissue contour at 4 months postextraction (H) alveolar ridge at 4 months postextraction and (I) CBCT volume rendering reconstruction at 4 months after tooth extraction.

after ARP.[30,78,84] Most of these reports concluded that there is a lack of concrete evidence demonstrating the superiority of a particular ARP technique, although the systematic review by Avila-Ortiz et al. (2019) determined that there was an advantage of using an absorbable collagen membrane for GBR when compared to a xenogeneic or allogeneic graft alone, when considering the preservation of the alveolar ridge width. Similarly, the meta-analysis by Troiano et al. (2018) reported on the superiority of the GBR technique when compared to bone grafting alone. Similar conclusions were drawn in a recent randomized controlled trial where GBR was found to be more effective than socket seal at reducing radiographic bone dimensional changes following tooth extraction in the anterior maxilla.[30] While the GBR technique was seen to be preferable to other ARP techniques, the advantage of using a specific graft or barrier membrane was undetermined.

The variability in the reported results could be attributed to the diversity of employed biomaterials and the variations in techniques and healing periods. Since the dimensional analysis in most of the controlled trials was made without taking into consideration the local and anatomic factors presented above, the average differences reported may not be representable of ARP efficacy in specific clinical scenarios. The beneficial effect of ARP over a simple extraction without ARP, in terms of preservation of alveolar ridge dimensions, may not be clinically significant in a case where the postextraction resorption is mild or moderate, for example, in a young, fit, and healthy individual, following the minimally traumatic extraction of a maxillary premolar with a thick and flat periodontal phenotype and >1 mm buccal wall thickness[18] (Figure 2). On the contrary, it could be speculated that in cases involving a maxillary anterior tooth, where the alveolar bone thickness is

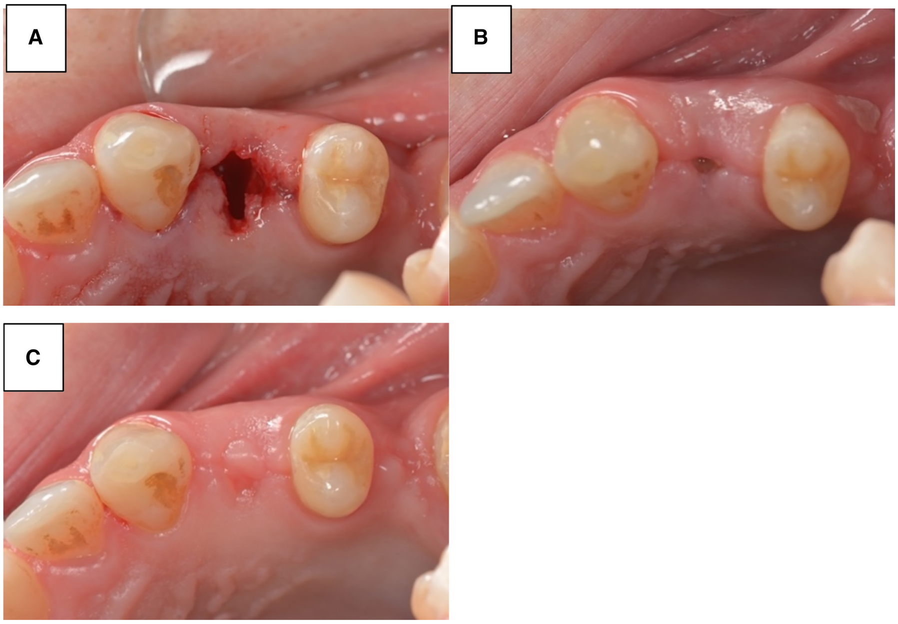

FIGURE 2 Photographs demonstrating unassisted socket healing protocol. (A) Clinical situation following tooth extraction 14. (B) Wound healing following extraction 10 days after. (C) Complete wound closure at 30 days after extraction.

<1 mm, ARP will be able to counteract and mitigate the significant reduction in the height and width of the alveolar ridge induced by the pronounced bundle none resorption.

In conclusion, local and systemic factors make postextraction bone resorption and remodeling unique for each individual and tooth site, resulting in different extent of ridge dimensional changes. The magnitude and timing of these dimensional changes will influence the complexity, costs, timing, and associated morbidity of treatment, directly impacting on the functional and aesthetic outcomes of any restorative treatment.[1,40,53,85] Knowledge of these factors and their possible interactions is essential for restorative treatment planning, as together with the practitioners' expertise and patient's expectations; they will define the choice of the most appropriate extraction site management and the timing of implant placement.

ARP could be considered in cases with a higher risk for bone resorption and soft/hard tissue loss, to facilitate and simplify future implant treatment, or improve the aesthetic outcomes of teeth-supported fixed restoration. The assessment of the facial bone wall thickness provides the practitioner with a prognostic tool to estimate the degree of future bone loss prior to tooth extraction. Therefore, the clinical decision-making process for ARP should start before tooth extraction and may involve an appropriate 3D radiographic analysis as part of a comprehensive restorative treatment plan.

A pre-extraction areal CBCT can help the practitioner defining both the labial and palatal wall thickness, the morphology, size and angulation of the socket, and/or its proximity to anatomical structures and neighboring teeth. These factors will influence a prosthetically driven implant placement, anticipate the difficulties associated with a minimally traumatic extraction, and calculate the benefit of performing ARP over immediate or delayed implant placement.

Although the magnitude of possible negative effects induced by systemic or behavioral conditions on ARP effectiveness remains unclear, the practitioner should take it under consideration when planning for ARP, since it could affect both grafting procedures and unassisted socket healing.

3 | NEW BONE FORMATION IN EXTRACTION SOCKET

3.1 | New bone formation in unassisted socket healing

The healing of the extraction socket is a complex, multifactorial process, characterized by the biologic paradox of concurrent alveolar tissue loss and formation. The coordinated but independent action of osteoblasts and osteoclasts will define the resorption of the socket wall and the formation within the socket of a provisional matrix. This provisional matrix subsequently becomes mineralized and will define not only the postextraction dimensions but also the histological composition of the alveolar ridge.

The osseous healing of the extraction socket is characterized by a sequence of histological events (inflammation, fibroplasia, mineralization, and remodeling) that is similar to the intramembranous bone formation observed in other type of alveolar osseous defects.[2] These events have been investigated in histological and histochemical studies in animals[3,5,86–90] and humans[7,91–96] while changes in hard tissue formation have also been evaluated in rats by means of radiographic densitometry[97] and in humans by subtraction radiography.[41] The process of postextraction osseous healing could be described in the following events:

- *Immediately after a tooth extraction*, blood from the severed blood vessels fills the extraction socket, triggering the release of plasma proteins (including plasminogen, fibrinogen, fibronectin, and albumin) and cell-mediated cytokines. This process initiates an inflammatory response and the aggregation of platelets, neutrophils, and red blood cells.

- *Within the first 12 h*, a provisional extracellular matrix is formed by the ongoing crosslinking of the fibrin meshwork and the conglomerate of platelets and endothelial cells.[98] This early fibrin clot acts as a seal for the wound and provides a physical matrix containing necessary growth factors for the migration, proliferation, differentiation, and synthetic activity of undifferentiated mesenchymal stem cells.[95]
- *At 2–4 days*, blood clot will start dissolving (*fibrinolysis*). Neutrophils and macrophages will migrate along the coagulum, phagocytize bacteria, and necrotic tissue being at the same time a source for growth factors and cytokines.[96]
- *At 4–6 days*, osteoclasts located on the original osseous walls will initiate a *bone resorption* process while epithelial tissue will proliferate apically into the socket area.[96]
- Undifferentiated mesenchymal cells will form a provisional collagen matrix (*fibroplasia*) which together with the newly formed blood vessels (*angiogenesis*) will replace the blood clot with granulation tissue by *Day 7*.[7]
- *At 1 week after extraction*, the transition of the provisional connective tissue into osseous tissue occurs along the vascular structures at the base and the side walls of the socket. Osteoprogenitor cells from the newly formed vessel endothelium (pericytes), or from the peripheral osseous surfaces and periodontal ligament remnants, will migrate into the wound area and differentiate into osteoblasts producing a collagen matrix with mineralized finger-like projections (*woven bone*).[96]
- *Osteoclastic resorption* continues on parts of the socket wall surface *after 10–12 days*, inducing at the same time more *synthesis of provisional matrix*.[92]
- *At 2–3 weeks after tooth extraction*, the newly woven bone is appositioned at the apical and lateral aspects of the socket, while the more central and marginal portions are occupied by dense connective tissue.[99] An *epithelial* “seal” of the socket entrance has been established *by 24–30 days* and epithelial down growth levels with the connective tissue in the coronal part of the socket. In the marginal and outer parts of the socket walls, *osteoclastic resorption* is still taking place.
- *At 4–6 weeks after tooth extraction*, increased number of osteoblasts and vascular structures drive the *mineralization of the woven bone* that has occupied most of the socket area replacing the provisional matrix/granulation tissue. In the outer and marginal portions of the buccal and lingual/palatal osseous walls, large numbers of osteoclasts contribute to the *ongoing bone resorption* causing a significant volumetric reduction in the alveolar ridge.[94]
- *At 8–12 weeks after extraction*, *bone maturation* occurs, with fewer osteoblasts and *retardation of osteogenesis*. Due to the *extensive remodeling of the osteoid*, lamellar bone with large marrow spaces is occupying most of the extraction site while the entrance of the socket is closed with cortical bone.[94]
- Although *little new bone formation* occurs *after 16–24 weeks*, *bone remodeling* still occurs at the extraction site at *6 months after the extraction* and is dependent on the functional loading and physiological development of the extraction site. Bone formation never reaches the pre-extraction bone levels since the resorption of the original socket walls at early healing stages has located postextraction alveolar ridge margins in a more apical position[7,91,100] (Figure 3).

The above time frames should be transitioned with caution to clinical practice. The postextraction socket healing is complete when the socket entrance is sealed with a cortical osseous bridge, covered by dense connective tissue and keratinized epithelium and the alveolus is reconstructed through bony infill. The timing of this healing process can be variable and dependent on local and systemic factors.[51] Although the provisional connective tissue matrix consistently forms within the first weeks of healing,[7,91,94,100] the timing and extent of its mineralization and remodeling process vary significantly between individuals where new bone formation may take >4 months to be completed. Trombelli et al. (2008) found that woven bone occupied 35% (2%–73%) of the healing socket area at 6–8 weeks of healing, whereas at 12–24 weeks, only 41% (8%–65%) of the socket area was comprised of mineralized tissue. Furthermore, only 1 of the 11 specimens, representing 12–24 weeks of healing, comprised lamellar bone and marrow, indicating that bone remodeling is slow and unpredictable in clinical conditions.[7]

The variable tissue composition of the healed alveolar ridge has been reported in histologic studies evaluating human biopsies from extraction sockets (Table 1). In a systematic review,[101] Chan et al. (2013) reported that the mean percentage of vital bone and connective tissue in natural healing sockets was 38.5% (±13.4%) and 58.3% (±10.6%), respectively. Currently, little is known on potential systemic or local factors affecting new bone formation, with the

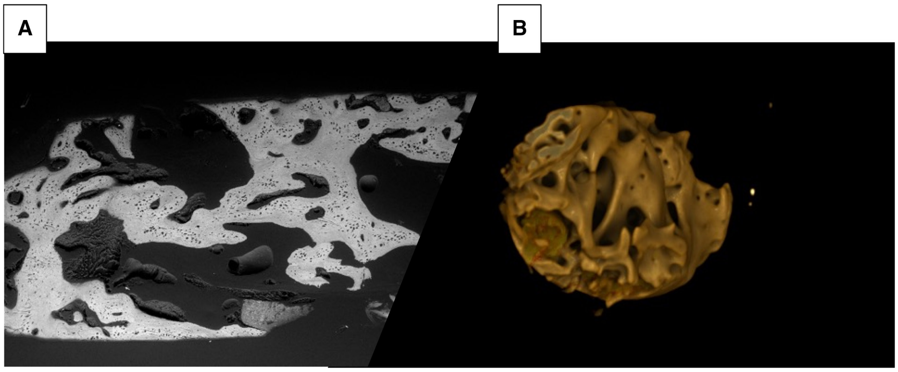

FIGURE 3 Comparison of BSE-SEM and XMT volume rendering images of new alveolar bone formation in an unassisted healing bone core sample. (A) BSE-SEM image. (B) XMT 3D volume rendering image presented in a 2D format.

TABLE 1 Selection of human studies evaluating mean percentage (%) of tissue composition (bone and connective tissue) of the healed alveolar ridge following unassisted socket healing.

Author	Bone (%)	Connective tissue (%)	Time period (months)
Aimetti et al. (2009)	47.2±7.7	65.5±25.85	3
Barone et al. (2008)	25.7±9.5	59.1±10.4	7
Carmagnola et al. (2003)	43.5	43	>9
Froum et al. (2002b)	32.4±6	51.6±36.1	
Guarnieri et al. (2004)	<46		3
Heberer et al. (2011)	44.21±24.88	55.78	3
Iasella et al. (2003)	54±12	46	4–6
Pelegrine et al. (2010)	45.47±7.21	65.50±25.85	6
Serino et al. (2003)	48.8±14.4	51.16±14. 43	3

majority of the available data based on preclinical studies[51] or anecdotal retrospective reports of compromised socket healing that has been associated with older age (>60), hypertension, or molar sites[102] etc. In one of the few human histological reports,[103] Lindhe et al. (2012) found that the relative volume of newly formed bone was greater in the mandible than in the maxilla (65% vs. 52%) and higher in the anterior part of the mandible (70% anterior vs. 61% posterior) after 6 months of healing. The authors also reported qualitative differences, with bone marrow being the predominant tissue in the anterior maxilla and dense lamellar bone in the anterior part of the mandible (62.6% ± 3.2 mandible and 46.1% ± 1.7 maxilla). The cortical bone bridge in the entrance of the sockets was thicker in the mandible (1.8 mm ± 0.2 mm) than in the maxilla (0.8 ± 0.1 mm), where its thickness was similar in the anterior and posterior regions (0.7 mm ± 0.1 verses 0.9 mm ± 0.1). The corticalization of the alveolar ridge of the residual alveolar ridge presented a similar inter- and intraindividual variation but was influenced by factors such periodontal disease and radiographic bone loss in the extracted teeth.[104,105]

3.2 | New bone formation in assisted socket healing—alveolar ridge preservation

One of the principal objectives for ARP is to promote physiological healing of the extraction socket with new bone formation[106] mitigating at the same time the dimensional alteration of the postextraction alveolar ridge, ensuring a stable hard and soft tissue foundation prior to prosthetic reconstruction.[30,77] Human histological reports have shown that healing following ARP was characterized by varying degrees of bone regeneration depending on the type of material/technique used and the healing period at assessment.[23,31,32,101,107] Consequently, the literature remains inconclusive on which technique or biomaterial is the most appropriate to promote new bone formation within the healing socket.[27] The efficacy and predictability of various ARP materials and techniques to promote new bone formation can be summarized in:

- *Autogenous bone chips* with a connective tissue graft as a *socket seal* resulted in 52% ± 8.6%[108] while bone marrow transplants achieved 42.9% of new bone formation.[109]
- *Allografts* presented a significant variation in the amount of new bone formation (Table 2) ranging between 12.98% of new bone formation after grafting with cancellous FDBA[110] and 52.7% of new bone formation after grafting with DBM allograft.[111] In a systematic review, Jambhekar et al.[107] found a mean percentage of only 29.93% of vital bone and 51.03% of connective tissue following ARP with allografts. The authors suggested that demineralized allografts (DFDBA) resulted in more (38.4% vs. 23.5%) new bone formation and less residual graft (8.8% vs. 26.94%), when compared to the nonmineralized freeze-dried forms (FDBA).[108] For this reason, Eskow and Mealey (2014) investigated the effect of a combination of FDBA and DFDBA combination and reported 41.5% of new bone formation and 3.45% of residual graft.[110] The addition of a PDGF growth factor,[112,113] collagen[114] or a $Ca(SO_4)$ barrier[115] was also found to increase the level of new bone formation after socket grafting with allografts. However, these percentages should be interpreted with caution considering that the different healing periods applied in the different studies may have influenced the histometric results. Interestingly, in their meta-analysis, De Risi et al.[31] reported a decrease in the average of new bone formation between 3 months (46%) and 7 months of healing (34%) when allografts were used for ARP.
- *Xenografts* of bovine, porcine, or equine origin have also achieved various amounts of new bone formation (Table 3) ranging from 9% when equine deproteinized bone mineral was used alone for socket grafting[116] up to 47% with bovine xenografts.[117] Da Rissi et al. (2013) reported the lowest new bone formation (24%) with ARP adopting xenografts procedures at 5 months of healing, although average new bone formation was increased at 7 months, which was similar to the changes recorded in allograft treated sockets (35%).[35] Similarly, Jambhekar et al. (2015) calculated a mean new bone formation percentage of 35.7%, with the remaining 44.42% being connective tissue.[108]
- *Alloplastic* bone graft substitutes presented variable percentages of new bone formation ranging from 21%[118] with a combination of b-TCP and PDGF growth factor to 66.7% with a resorbable polymer sponge[119] (Table 4). Bioactive glasses[120,121] also promoted bone healing of >50%. In their meta-analysis, Da Rissi et al. (2014)[35] found that alloplastic materials provided the best new bone formation average (54% and 48%) and the lowest amount of connective tissue (24% and 28%), when all the tested bone grafts and substitutes were reviewed at 3 and 7 months of healing. This finding is in contrast to what was observed with allografts, as

TABLE 2 Selection of human studies evaluating histological characteristics of sockets augmented with allografts.

Author	Time	Material	Bone (%)	Fibrous/connective tissue (%)	Graft matrix (%)
Eskow and Mealey (2014)	18.2 weeks	Cortical FDBA	16.08 (12.12–30.25)	52.9 (47.4–57.08)	28.38 (18.47–37.52)
		Cancellous FDBA	12.98 (10.06–31.04)	62.82 (50.89–68.51)	19.94 (15.82–24.33)
Hoang and Mealey (2012)	20 weeks	DBM	48.8 ± 18.7	43.1 ± 18.6	8.2 ± 4.7
		Allograft	52.7 ± 13.1	41.9 ± 11.5	5.4 ± 4.5
Wallace et al. (2013)	4 months	Allograft	32.5		
		Allograft + PDGF	41.8		
Nevins and Reynolds (2011)	5 months	Mineral collagen bone substitute	28.3 ± 17.2		
		+ PDGF	39.6 ± 11.3		
		+ EMD	23.9 ± 9.3		
		EMD + bone ceramic	21.4 ± 4.2		
Chang et al. (2009)	12 weeks	Control	1.39 ± 0.15		
		Hydroxyapatite/collagen gel bead + PRP	61.83 ± 9.35		
Vance et al. (2004)	4 months	Allograft + $CaSO_4$ barrier	61 ± 9		

Abbreviations: $CaSO_4$, calcium sulfate; EMD, enamel matrix proteins; FDBA, freeze-dried bone allograft; PDGF, platelet-derived growth factor; PRP, platelet-rich plasma.

TABLE 3 Selection of human studies evaluating histological healing characteristics following alveolar ridge preservation (ARP) with xenograft materials.

Author	Time (months)	Material	Bone (%)	Fibrous/connective tissue (%)	Graft matrix (%)
Cook and Mealey (2013)	5	Bio-Oss® Collagen	32.83 ± 14.72	53.73 ± 6.76	13.44 ± 11.57
		Xenograft sponge + bovine collagen	47.03 ± 9.09	52.9 ± 9.09	0.0
Park et al. (2010)	4	Equine BM	9.88 ± 6.57	47.5 ± 9.28	42.62 ± 6.57

TABLE 4 Selection of human studies evaluating histological healing characteristics following alveolar ridge preservation (ARP) with alloplast materials.

Author	Time (months)	Material	Bone (%)	Fibrous/connective tissue (%)	Graft matrix (%)
McAllister et al. (2010)	3	PDGF + Bio-Oss®	24		
		PDGF + b-TCP	21		
Clozza et al. (2014)	6	Bio-glass	54 ± 31		8.1 ± 7.8
Froum et al. (2002a)	6–8	Bioactive glass	59.5		5.5
Serino et al. (2003)	6	Bioabsorbable synthetic sponge of polylactide-polyglycolide	66.7		

Abbreviations: HA, hydroxy-appetite; TCP, tri-calcium phosphate.

increasing the healing period, did not produce a marked increase or decrease in new bone formation.[35]

- *Absorbable and nonabsorbable barrier membranes for GBR* combined with different bone grafts and substitutes, resulted in predictable but variable bone formation around the graft particles as early as 3 months of healing.[31,32,101] Consequent meta-analyses have revealed more bone formation when the various bone grafts were combined with a membrane in comparison to the sole use of grafts.[32,101] On the contrary, the addition of bone grafts or substitutes under barrier membranes have not been adequately investigated. Previous studies that evaluated new bone formation under GBR collagen barriers without any bone grafts reported

45.9%±12.4 of new bone formation at 3 months of healing.[122] The same systematic reviews identified the combination of collagen barriers and xenografts as the most commonly investigated ARP technique, but failed to identify the superiority of a specific graft-membrane combination over another.

- The histological outcomes of *socket seal (SS)* technique have not been extensively investigated (Table 5). Maiorana et al.[123] used bovine bone mineral to graft fresh extraction sockets and a porcine collagen matrix to seal their entrance. Histomorphometric analysis of SS ARP sites reveal 16.0%±7.1 of new bone formation with 50.7%±8.4 of connective tissue. A similar delayed healing pattern was also shown by Geurs et al.[95] who investigated socket healing following socket seal at 8 weeks using FDBA, beta-TCP, FDBA/beta-TCP/PRP, and FDBA/beta-TCP/PDGF grafts, in association with a collagen plug. This study concluded that the presence of bone graft suppressed new bone formation during the early stages of healing, but that all treatment modalities achieved a significant amount of additional new vital bone formation, when compared to nongrafted sockets.

Although ARP techniques are more effective than unassisted socket healing in preserving alveolar ridge dimensions and contour,[23,27,30] they have limited benefit on new bone formation when compared to naturally healing sockets.[31,32,101] A network meta-analysis[32] evaluating the histological outcomes after ARP with various biomaterials showed that the majority of available grafting materials was not able to improve new bone formation at 3–6 months, postextraction. Nine out of the 34 investigated grafts, including the most extensively researched forms of xenografts (deproteinized bovine bone mineral with or without collagen) and allografts (FDBA) achieved significantly less new bone formation than the empty non-grafted sockets, while 25 grafting materials achieved similar amounts of new bone formation. Plasma rich in growth factors (PRGF) was the only grafting material that resulted in a higher percentage of more new bone formation than unassisted socket healing.[33]

The use of bone grafts and substitutes for ARP assumes that they will act as an osteoconductive scaffold which will support blood clot stability during the early phases of healing and/or promote osteoinductive factors that will induce osseous formation by the differentiation of mesenchymal cells into osteoblasts. Ideally, bone grafts or bone substitutes should be progressively resorbed and substituted by the newly formed bone. Slow substitution rate bone grafts could potentially be advantageous in preserving the alveolar ridge volume since they can maintain their integrity over a longer term, being in direct contact with newly formed bone or dense connective tissue. High substitution rate materials degrade through osteoclastic resorption[124] and could be potentially better in promoting new bone formation[125] but may suffer from poor mechanical properties. In the case of ARP, a slow absorption rate and higher levels of residual graft particles have been associated with reduced new bone formation and a delay in bone regeneration and remodeling.[32,95,126–128] Residual graft particles which are often surrounded by connective tissue and variable amounts of new bone[129–131] may invoke a giant cell, foreign body response and delay the activation of the osteoclastic process[132] interfering with physiologic bone healing at the extraction site. Moreover, the residual graft particles occupy additional space and therefore limit the anticipated area of new bone formation.[133,134] Reduced amounts of new bone formation have been associated with higher amounts of residual xenograft,[44,116,117,127,135,136] allografts[49,137] and alloplasts.[126,138] While new bone formation was variable, the absorption rate of all these grafting materials was also unpredictable.[32,49,107,139] Artzi et al.[130] and Carmagnola et al.[131] suggested that ARP with xenografts, resulted to 30–40% of residual graft matrix at 9 months, with the retained particles surrounded by vital, newly formed bone. In the meta-analysis by De Risi et al.,[35] xenografts and alloplasts presented the highest amounts of residual graft particles; 37.1% and 37.2%, respectively, and although the allografts presented the lowest amounts of residual particles (12.4%) after 7 months of healing, no statistical significant difference was identified between the different materials. Similarly, Canellas et al.[32] showed no statistical difference in the percentage of residual graft particles between different biomaterials at 3–6 months of healing.

It can be concluded that bone grafts and substitutes do not accelerate bone healing or induce more new bone formation in osseous defects when reviewed against the intrinsic bone regeneration potential of the extraction socket. Grafts with slow absorption rate (xenografts and allografts) could be more effective in maintaining postextraction alveolar ridge volume than grafts with faster resorption rates (alloplast and composite ceramic)[30,78] but the higher amounts of residual graft material may have a negative impact on the amount of new bone formation.[140] The practitioner therefore needs to balance the preferential effects of ARP on soft tissue and hard

TABLE 5 Selection of human studies evaluating histomorphometric analysis of alveolar ridge preservation (ARP) sites following ARP with various soft tissue graft to seal the entrance of the socket.

Author	Time	Material	Bone (%)	Fibrous/connective tissue (%)	Graft matrix (%)
Maiorana et al. (2017)	6 months	DBBM + Collagen Matrix	16.0±7.1	50.7±8.4	
Geurs et al. (2014)	8 weeks	Collagen plug	0	46	
		FDBA + b-TCP + Collagen plug	35	25	
		FDBA + b-TCP + PRP + Collagen plug	28	22	
		FDBA + b-TCP + PDGF + Collagen plug	18	28	

tissue contour preservation, against the risk of compromised bone formation. Although the quantity of newly formed bone and potentially the quality of the osseointegration of dental implants placed into previously augmented sockets with osteoconductive graft scaffolds may be inferior to those achieved in unassisted socket healing,[49,80] this does not seem to influence implant placement feasibility and osseointegration in their short-term survival and success rates.[9,30,78,141] Furthermore, there is no available literature to suggest that implants placed in ARP-treated sockets are more susceptible to peri-implant diseases than implants placed in pristine bone.

4 | DOES ALVEOLAR RIDGE PRESERVATION IMPROVE THE CLINICAL OUTCOMES OF DENTAL IMPLANTS?

The goal of ARP is to preserve the existing soft and hard tissue envelope and maintain a stable alveolar ridge volume to simplify implant placement and improve their functional and aesthetic outcomes[23,106] (Figure 4). Taking this goal under consideration, ARP can be classified as a preprosthetic surgical procedure that may increase the cost, complexity, and treatment timeline for rehabilitation of the patients. It is therefore essential to define whether there is an added benefit or value for ARP over unassisted socket healing, in terms of implant-related outcomes such as implant placement feasibility, need for further augmentation during implant placement, survival, success rates, and incidence of biologic or other complications.[9]

Although some systematic reviews have shown that implant placement feasibility was comparable in patients treated with ARP or left for unassisted socket healing[9,25] there is no clear evidence on how ARP procedures may influence implant placement feasibility in comparison with unassisted socket healing.[31,81] It could be argued that specific ARP techniques and materials may influence implant placement feasibility in specific surgical situations, such as the anatomic location, the angulation of implant placement according to a prosthetically driven placement protocol, or the diameter of the used implants, influenced both the placement feasibility, and the need for further ridge augmentation.[9]

Clinical trials that investigated the requirement for additional bone augmentation at the time of dental implant placement reported that the application of ARP may reduce the need for further, simultaneous bone augmentation at implant placement.[47,49,65,72,73,142–146]

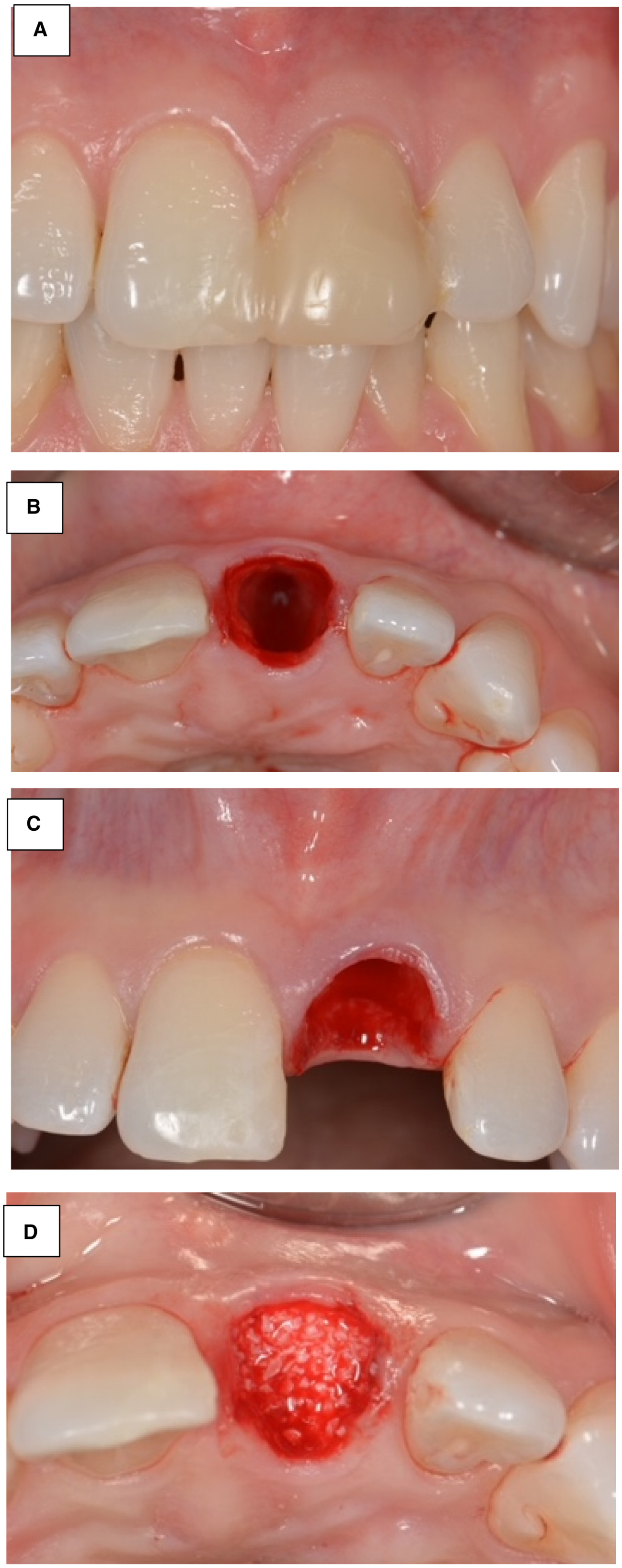

FIGURE 4 Photographs illustrating the surgical protocol for ARP with the SS technique: (A) Upper left central incisor before extraction, (B, C) Minimally traumatic tooth extraction following intracrevicular incision without involving the gingival papillae and e-epithelialization of the gingival tissue collar, (D) Filling of the gingival socket with a xenograft (E) The porcine collagen matrix was sutured to seal the socket aperture, (F, G) soft tissue healing of the ridge at 4 months postextraction, (H) Periapical X-ray showing hard tissue formation within the area of the extraction socket, (I, J) preservation of alveolar ridge dimensions before (I) and after implant osteotomy (J), (K) Periapical X-ray after implant placement, (L) final implant-supported restoration at implant loading.

Mardas et al. (2015)[9] calculated that ARP reduced the need for further augmentation during implant placement by 85%, while the reduction in the need for bone grafting prior to or at the time of implant placement ranged between 55% and 100% in the systematic

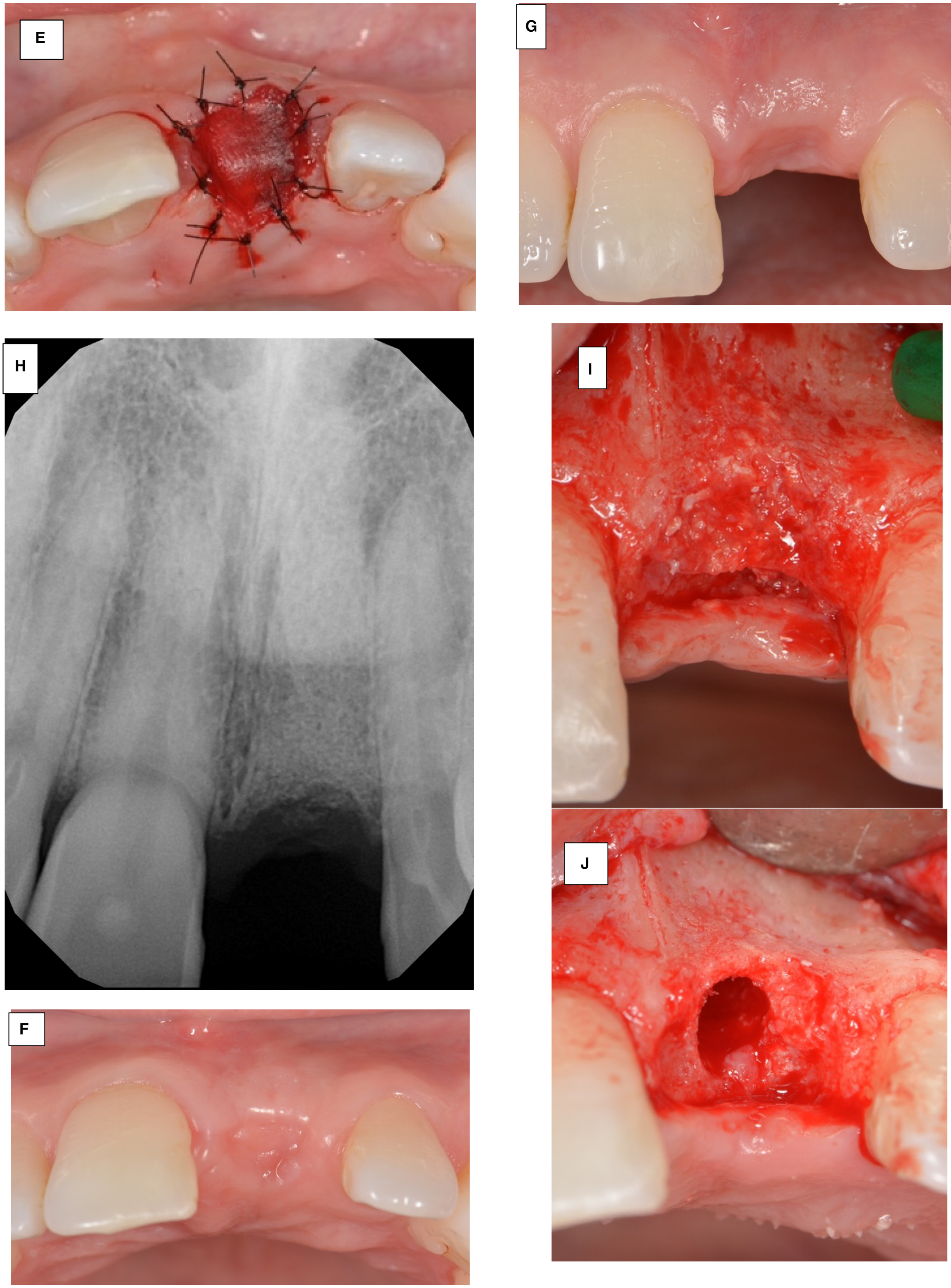

FIGURE 4 (Continued)

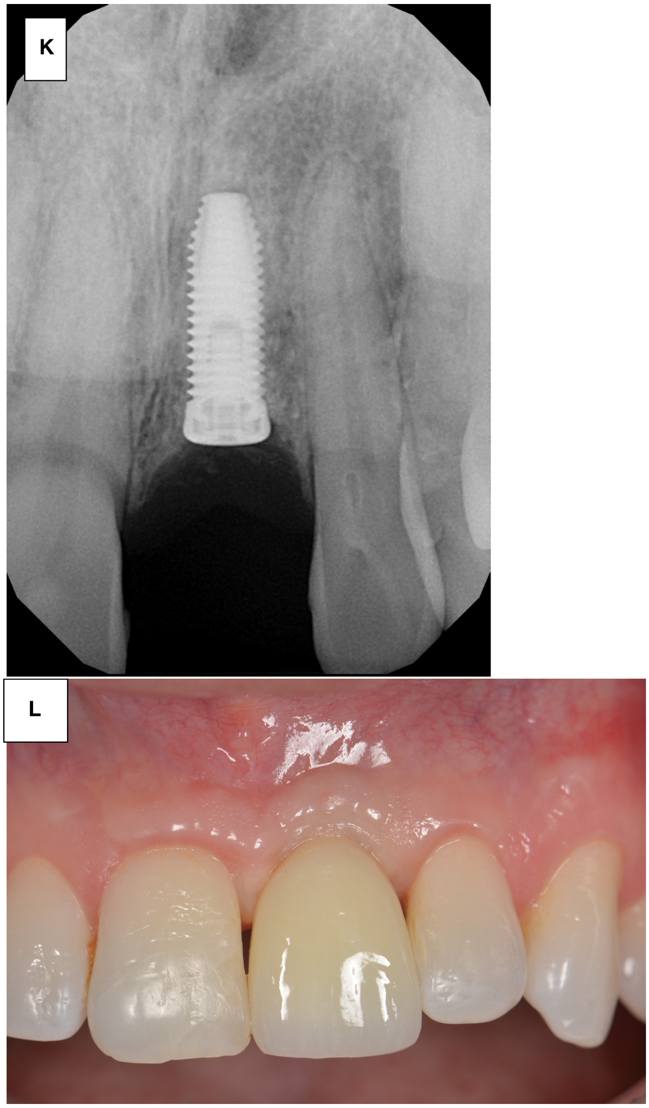

FIGURE 4 (Continued)

review by Avila-Ortiz et al.[33] These observations were confirmed in three recent randomized control trials not included in these two meta-analyses. Avila-Ortiz et al.[74] showed that additional GBR was required in 48.1% of unassisted socket healing sites and only in 11.5% of ARP sites treated with an allograft and a nonresorbable membrane. Similarly, Macbeth et al. (2022)[32] reported that patients presented with significantly less need for GBR due to a dehiscence or fenestration defect at implant placement, when ARP with xenograft bone graft substitute (DBBM) and collagen barrier membrane or collagen matrix seal was performed 4 months before implant placement. Finally, Jonker et al.[47] reported that GBR was indicated in 72% of the unassisted socket healing cases but only in 24% and 32% of the cases were a xenograft covered with a free gingival autograft or with a porcine collagen matrix was used with a socket seal technique. Furthermore, ARP in maxillary molars resulted in reduced need for sinus augmentation compared with spontaneous socket healing, since it maintained the vertical bone height more efficiently.[147]

There are very few studies available evaluating long-term survival and success rates of implants placed in grafted alveoli.[148–151] A prospective study by Jung et al. 2013[152] assessed the survival of implants placed in grafted alveolar ridges and showed a survival rate of 97.2% and 95.2% at 5 and 10 years; these figures being comparable to the reported survival rates of single implants in pristine bone. Tran et al.[148] compared implant survival rates following ARP over a 5- and 10-year review period. Despite a 2% and 7% reduction in survival rates for the ARP group, no statistical difference in the survival rate was found when comparing implants which were placed in native bone, or bone-grafted sites.[148] These findings are in line with other systematic reviews, demonstrating that in the short term, implants placed in previously grafted sockets presented similar and high survival and success rates, without significant proximal bone loss with implants placed following unassisted socket healing.[9,23,30,78]

In conclusion, there is limited evidence to support the clinical benefit of any ARP technique over unassisted socket healing, when considering implant outcomes, with survival, success rates, and marginal bone levels of implants placed in ARP sites, comparable to that of implants placed in untreated sockets.[26,77] While implant placement feasibility was similar in both ARP and unassisted healing, the ability to adopt a prosthetically driven implant placement following different ridge preservation techniques remains unclear. Although ARP may decrease the need for further bone augmentation during implant placement, in comparison with unassisted socket healing, this may not be a salient clinical benefit for the experienced practitioner who is confident in applying GBR procedures for the management of moderate buccal osseous defects around implants placed using a Type 2 or Type 3 protocol. Current literature has presented high levels of survival and success rates with this treatment approach which can predictably translate into satisfactory aesthetic outcomes.[20,153] On the contrary, the application of ARP may potentially simplify the surgical treatment during implant fixture placement, eliminating the need for additional GBR, or limiting the extend of the peri-implant defects to be treated which may be beneficial to less experienced practitioners. Patient preference and the type, cost, and timing of the restorative treatment may often guide these treatment decisions. Based on current evidence, a smaller yet significant number of patients who undergo ARP during tooth extraction may require additional bone grafting during implant placement, resulting in increased costs and morbidity. Moreover, recent research on alveolar ridge preservation therapy suggests that higher spending on allogeneic and xenogeneic bone graft materials does not necessarily equate to increased effectiveness. However, an observable correlation exists between the investment on a barrier membrane and decreased horizontal and vertical ridge resorption, but only up to a certain extent before the return on investment decreases significantly.[154] This underscores the need for further research on the cost-effectiveness of various therapeutic modalities regarding patient-related outcome measures, including a comprehensive cost–benefit analysis of all alternative procedures.

5 | WHAT IS THE IMPACT OF ARP TO THE PERI-IMPLANT SOFT TISSUE PHENOTYPE?

The success of an implant-supported restoration is closely associated with the dimensions and morphology of the bone-soft tissue complex that surrounds and supports the implant fixture.[19,155,156] This complex has been recently described as the peri-implant phenotype and is composed of a soft tissue component that includes the peri-implant keratinized mucosa width and thickness, the supracrestal mucosal tissue height, and an osseous component, characterized by the peri-implant bone thickness.[157] All three soft tissue components of the peri-implant phenotype have been associated with a different extent, with peri-implant health and aesthetic outcomes.[19,158] Besides some early conflicting reports,[159] more recent studies have suggested that a deficient zone of peri-implant keratinized mucosa (<2 mm) could be related to more plaque accumulation, tissue inflammation, and recession,[160–162] an increased risk for peri-implant mucositis[163] and lower patient aesthetic satisfaction.[164] Thick (≥2 mm) peri-implant mucosa[157] prevented soft tissue recession[165] and resulted in less proximal bone loss.[156] Finally, short supracrestal tissue height (<3 mm), as measured from the bone crest in an apico-coronal direction over the implant shoulder, was associated with greater marginal bone loss.[166,167] Based on these findings, current consensus papers supported the use of soft tissue grafting augmentation procedures for peri-implant soft tissue phenotype modification, as a way to promote and secure peri-implant health.[158]

Prior to tooth extraction in the anterior maxilla, the buccal soft tissues are usually thin, ranging between 0.5 and 1 mm,[145,168–171] with the maxillary canines and mandibular first premolars recorded as having the thinnest gingival tissue (0.7–0.9 mm) with a relatively higher incidence of gingival recession.[172,173] A direct correlation between the pre-extraction gingival tissue thickness and the underlying socket wall thickness has been disputed.[168,174,175] The postextraction alveolar ridge resorption will affect the soft tissue dimensions by leading to a narrowing of the keratinized mucosa, changing the soft tissue thickness and volumetric reduction in the external soft tissue ridge contour.[41,144,176] The soft tissue dimensional changes after tooth extraction are patient and site specific, and like the hard tissue changes, they are influenced by the morphology of socket, although they do not necessarily correspond to the resorption patterns of the alveolar bone.[53,72] For example, in an area with a thin bone morphotype, a spontaneous soft tissue thickening may take place within the first 2 weeks of healing, as compensation to the more pronounced osseous resorption of the socket walls.[176] These dimensional changes are particularly evident in the anterior part of the mouth of patients with a thin-scalloped phenotype, where the thinner bone wall and gingival thickness may result in increased buccal bone resorption but concomitantly to an increased mucosal thickness.[17] When considering the possible benefits of this biological paradox, it is worth remembering that the localized mucosal thickening is masking the true extent of underlying bone resorption, maintaining the original external soft tissue contour of the residual ridge.[72] This soft tissue compensation may facilitate the soft tissue management during future implant surgery,[177] reducing the indications for soft tissue augmentation surgery at a later stage.[53]

The efficacy of various ARP techniques to improve soft tissue outcomes has been evaluated in clinical trials with variable and contradictory results.[27,178] Keratinized tissue changes have not been adequately investigated following ARP. ARP techniques utilizing GBR resorbable barriers appeared to result in a small increase in the keratinized tissue width, when compared to unassisted socket healing, when a flapless approach with no attempt for primary closure was undertaken.[65,179,180]

In a recent trial,[144] Thoma et al. (2020) reported a moderate size effect on improving mucosal thickness following ARP when using a xenograft and a collagen matrix with a socket seal technique. The investigators recorded a median mucosal thickness of 3 mm at the grafted sockets, at 2 months healing, compared with only the 1.5 mm found in spontaneous socket healing. However, several other studies found that mucosal tissues were thinner in ARP-treated sites, in comparison with simple extraction, when GBR collagen membranes and various grafts were used.[49,115,180,181]

In contrast to the studies that reported that socket seal utilizing a xenograft and a free gingival graft[182,183] was able to limit the postextraction external soft tissue contour shrinkage, no significant differences in soft tissue contour changes were reported when ARP with a nonresorbable d-PTFE membrane and an allograft,[72] a collagen membrane and a bovine xenograft,[184] a xenograft, and a free gingival graft or a porcine collagen matrix as socket seal[34] were compared with unassisted socket healing. The findings of a recent systematic review and network meta-analysis[185] concluded that hard and soft tissues behave differently after ARP as a response to the choice of the biomaterials used. According to their analysis, there is moderate evidence that crosslinked collagen membranes[186] and the use of autogenous soft tissue grafts to seal the entrance of the socket was more effective in terms of maintaining soft tissue dimensions. On the contrary, there is no robust evidence indicating that the type of socket graft may directly affect soft tissue dimensional changes. The heterogeneity in case selection, surgical protocols, measurement techniques for soft tissue dimensional changes, and follow-up durations in the included studies are the main limitation when drawing definite conclusions regarding the efficacy of specific techniques and materials for ARP, when acting to improve soft tissue outcomes.

In summary, soft tissue dimensions play an important role in implant site development and the maintenance of peri-implant health, but the impact of soft tissue alterations in postextraction sites has not been fully elucidated by current clinical research.[28] The relative contribution of the soft and hard tissues dimensional changes on the residual alveolar ridge volume and contour and the biological interplay between soft and hard tissue in the healing of extraction site is still poorly understood.[183] Barring hard tissue preservation, the application of ARP aims to optimize soft tissue quality and quantity during socket healing. Although some studies have reported that some ARP techniques and materials are capable of mitigating the extent of soft tissue dimensional changes postextraction,[144,183,185,186] keratinized mucosa width, mucosal thickness, and the external soft tissue contour are not significantly different between alveolar ridges healed with or without ARP.[27,72,184] This lack of difference has been attributed to a great extent to a soft tissue thickening in spontaneous healing sites, especially when the buccal osseous wall is thinner than 1 mm.[53,72,184] Based on these data, ARP may be considered less critical for soft than hard tissue preservation and a cost–benefit evaluation should be applied when a tooth-supported bridge/ prosthesis is planned.[184] Furthermore, the application of the ARP procedures frequently involves specific surgical manipulations, that may result in undesirable consequences to the mucosal tissue healing in the hands of less experienced clinicians. Postoperative complications include gingival marginal recession, loss of keratinized tissue, reduced interdental papillary height, reduced tissue thickness, alteration to

TABLE 6 Summary statements one the evidence pertaining to the key objectives of alveolar ridge preservation (ARP) against unassisted socket healing (USH).

Postextraction dimensional changes in alveolar ridge	
USH (+/−)	• Following tooth extraction, the bundle bone resorption leads to significant dimensional changes in the alveolar ridge. • The postextraction ridge resorption and remodeling rate varies vastly among patients and is dependent on several systemic and local factors. • The pattern and the extent of the alveolar ridge resorption is influenced by anatomical differences such as the location of the extraction site and the alveolar process morphology. • The periodontal phenotype, which represents both the thickness of the buccal and lingual/palatal soft tissue and the height of the underlying bone, may also affect postextraction ridge resorption.
ARP (+)	• Systematic reviews and meta-analyses have demonstrated that ARP results in less reduction in vertical mid-buccal bone height and less reduction in horizontal bone width[27,30] when compared to unassisted socket healing. • The effectiveness of ARP techniques varies depending on the biomaterials used, techniques employed, and healing periods. The choice of the most appropriate ARP technique depends on various factors, and the effectiveness of a particular technique over another remains undetermined. • The beneficial effect of ARP may not be clinically significant in cases where a limited postextraction resorption is expected, while it could be more effective in cases involving a maxillary anterior tooth where the alveolar bone thickness is <1 mm.
New bone formation in extraction socket	
USH (+/−)	• The healing of the extraction socket is a complex, multifactorial process that involves alveolar tissue loss and formation. • The timing and amount of new bone formation can vary depending on local and systemic factors. Bone formation never reaches the pre-extraction bone levels due to the resorption of the original socket walls.
ARP (+/−)	• Most of the currently used biomaterials for ARP do not accelerate bone healing or induce more new bone formation in osseous defects when compared against unassisted socket healing. • Absorbable and nonabsorbable barrier membranes for GBR combined with different bone grafts and substitutes have resulted in predictable but variable bone formation, with more bone formation observed when membranes were used in combination with grafts. • Although the quantity of newly formed bone following ARP may be inferior to that achieved in unassisted socket healing, implant placement feasibility, osseointegration, survival and success rates, and susceptibility to peri-implant diseases are similar to those of implants placed in pristine bone.
Dental implant survival and success	
USH (+)	• Implants placed in ARP-treated sockets have comparable survival and success rates to those placed in untreated sockets.
ARP (+)	
Dental Implant placement feasibility	
USH (+/−)	• Implant placement feasibility may be influenced by specific ARP techniques and materials in certain surgical situations. • ARP can increase the cost, complexity, and treatment timeline for patients, so it is important to determine whether there is added benefit over unassisted socket healing.
ARP (+)	
Need for bone grafting	
USH (−)	• ARP may reduce the need for further, simultaneous bone augmentation at implant placement, and can result in reduced need for sinus augmentation in maxillary molars.
ARP (+)	
Peri-implant soft tissue phenotype	
USH (+/−)	• Soft tissue dimensions and external ridge contour change after tooth extraction and are influenced by the socket morphology and periodontal phenotype. • The efficacy of various ARP techniques to improve soft tissue outcomes is variable and contradictory.
ARP (+/−)	

Note: (+) evidence in favor of using ARP or USH. (−) evidence against the use of ARP or USH (+/−) inconclusive evidence in favor of the use of one or the other approach.

the muco-gingival line,[187] and scarring of the soft tissues that may influence the future aesthetic outcome of implant treatment.[188]

6 | CONCLUSIONS—WHEN SHOULD PRACTITIONERS CONSIDER ARP FOLLOWING TOOTH EXTRACTION?

- ARP is an evidence-based, clinically validated, and safe approach for extraction site management, that in specific clinical occasions will facilitate implant placement in a prosthodontic-driven position, mitigating the dimensional soft and hard tissue loss that takes place after tooth extraction (Table 6).
- In specific clinical scenarios, ARP reduces not only the indications but also the extent and complexity of additional bone augmentation procedures at the time of or prior to implant placement, something that may be of substantial clinical benefit to less experienced practitioners.
- Despite the fact that many current bone grafting materials used in ARP do not show a significant increase in new bone formation compared with unassisted socket healing, research suggests that the osseointegration survival and success rates of implants are not negatively impacted. ARP has limited effect on improving the soft tissue quality or quantity of the healed alveolar ridge.
- Although the use of barrier membranes over a bone graft or substitute has been proven as the most predictable current protocol for ARP, the membrane or graft biomaterial of choice and the most appropriate surgical protocol for their application have not yet been defined.

Dental practitioners may consider ARP in:

- Clinical situations when the implant placement should be delayed after tooth extraction and a Type 1 or 2 implant placement is not indicated, for example, young patients, management of primary disease in the remaining dentition, and patient's preference.
- When the time, complexity, cost and associated morbidity, and risks of the expected alternative bone augmentation procedure or immediate implant placement are not compatible with patient's expectations or practitioner's expertise.
- Clinical situations in which minimizing alveolar ridge dimensional changes is critical, such as
    - ○ Extraction sites (especially those with aesthetic importance) presenting a thin buccal bone plate (<1 mm), where extensive postextraction resorption and dimensional loss of the alveolar ridge should be anticipated and may jeopardize implant placement.
    - ○ Posterior sites exhibiting limited ridge height postextraction, which may lead to implant proximity to the maxillary sinus or
- A pre-extraction areal CBCT can help the practitioner define the labial and palatal wall thickness, the morphology, size, and angulation of the socket, anticipate the difficulties associated with a minimally traumatic extraction, and calculate the benefit of performing ARP over immediate or delayed implant placement. The practitioner should also consider the possible negative effects induced by systemic or behavioral conditions on ARP effectiveness when planning for ARP.

CONFLICT OF INTEREST STATEMENT

I certify that I have no commercial associations (e.g., consultancies, patent-licensing arrangements, and equity interests) that might represent a conflict of interest in connection with the submitted manuscript.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analysed in this study. All data presented in this paper has already been published.

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