Efficacy of Augmentation Materials and Surgical Methods in Alveolar Ridge Preservation Post-Tooth Extraction

Xinda Li, Attila Horváth

Department of Periodontology, Faculty of Dentistry, Semmelweis University, Budapest, Hungary

Abstract

AIM: To evaluate the clinical and radiographic outcomes of various augmentation materials and surgical techniques in alveolar ridge preservation procedures compared to natural post-extraction socket healing.

METHODS: A literature search was conducted using the PubMed/MEDLINE database, focusing on the efficacy of different augmentation materials. The initial search yielded 291 studies, which were screened to exclude duplicates and irrelevant entries. Full texts of potentially relevant articles were assessed based on predefined inclusion criteria: studies had to be randomized controlled trials or clinical studies with a minimum follow-up of two months.

RESULTS: In total, 19 studies were ultimately included into the analysis. Alveolar ridge preservation (ARP) procedures are more effective than natural healing in minimizing post-extraction bone resorption, preserving both horizontal and vertical bone dimensions. Cortico-cancellous porcine bone particles and alloplastic materials yield superior results in maintaining alveolar ridge dimensions compared to control groups. Platelet-rich fibrin also reduces bone resorption and enhances preservation. Barrier membranes in ARP procedures further improve outcomes.

CONCLUSION: Future research should refine ARP techniques and materials, focusing on long-term effectiveness and practicality. Investigations into cost-effectiveness and ease of application will promote broader adoption. By implementing tailored ARP strategies, dental professionals can enhance the long-term success of restorations, sustaining patients' health, function, and aesthetics.

* * *

Archive of Orofacial Data Science

Accepted: Friday 20th September, 2024. **Data availability statement:** All relevant data are within the article or supplement files unless otherwise declared by the author(s).

1 Introduction

Tooth extraction is a common procedure in daily dental practice, frequently due to untreated periodontal diseases and periapical lesions, sometimes caused by traumatic injury to the teeth (Schropp et al., 2003b; Horváth et al., 2013; Mardas et al., 2015; Joshi et al., 2016). To address the need to maintain or restore acceptable conditions for sustained health, function, or aesthetic demands, especially when a fixed dental prosthesis or implant-supported restoration is needed in the future, a surgical procedure called "alveolar ridge preservation" or "socket preservation/sealing" has been introduced (Johnson, 1969; Darby et al., 2009; Gerritsen et al., 2010; Morjaria et al., 2014; Avila-Ortiz et al., 2014a; MacBeth et al., 2017).

After extraction, the absence of the tooth in the alveolus activates a cascade of biological events that typically result in dimensional changes, most notably local anatomical alterations (Atwood, 1971; Chen & Buser, 2009; Avila-Ortiz et al., 2014a; Mardas et al., 2015). This occurs because the alveolar process is a tooth-supported anatomical structure. Furthermore, during the healing phase post-extraction, the alveolar bone undergoes additional atrophy due to the natural remodelling process (Amler et al., 1960; Boyne, 1966; Amler, 1969; Horváth et al., 2013; Mardas et al., 2015). These physiological changes have been documented to cause more than 50% width and height resorption after three months of healing, or 63% and 22% dimensional loss in the horizontal and vertical aspects, respectively, six months post-extraction (Atwood, 1971; Joshi et al., 2016). Additionally, narrowing of the keratinised mucosa and a reduction in volumetric tissue thickness will also occur (Tarnow et al., 1996; Schropp et al., 2005; Darby et al., 2009; Thoma et al., 2009; MacBeth et al., 2017).

Moreover, current systematic reviews highlight that the height resorption of alveolar ridge defects (mean value of 1.67 mm) is more pronounced in the lower jaw than in the upper jaw (Atwood, 1971; Wood et al., 1972; Van der Weijden et al., 2009; Tan et al., 2012; Leblebicioglu et al., 2013; Jamjoom & Cohen, 2015; MacBeth et al., 2017). Additionally, alveolar ridge width loss (mean value of 3.87 mm) is more significant in the buccal plate of both the maxilla and mandible. Consequently, the alveolar ridge margin will shift more towards the lingual/palatal position over time (Atwood, 1971; Tan et al., 2012; Morjaria et al., 2014; Mardas et al., 2015). Furthermore, other clinical studies indicate that the elevation of a full-thickness mucoperiosteal flap during surgery may result in approximately 0.6 mm of crestal bone loss following tooth extraction (Wood et al., 1972; Jamjoom & Cohen, 2015).

To counter these adverse effects, the purpose of the alveolar ridge preservation (ARP) procedure is to mitigate the adverse effects of post-extraction resorption and maintain the alveolar ridge's hard and soft tissue dimensions (Horváth et al., 2013; Mardas et al., 2015). Several surgical techniques have been discussed in the literature, including guided bone regeneration (GBR), socket sealing, and socket filler (Lekovic et al., 1997; Iasella et al., 2003; Mardas et al., 2015).

Additionally, various grafting materials have been documented, including autogenous bone grafts, allografts (mineralised freeze-dried bone allograft), xenografts (deproteinised bovine bone), alloplastic polymers, composite ceramic material, bioactive glass, and autologous growth factors (PRF). Furthermore, different soft tissue grafts, such as autogenous free gingival grafts, dermal allografts, or collagen matrix xenografts, have been employed to "seal" the socket entrance (Jung et al., 2004; Wang & Lang, 2012; Horváth et al., 2013; Jung et al., 2013a; Avila-Ortiz et al., 2014b; Mardas et al., 2015).

For optimal results, the ideal graft materials should exhibit properties of osteoinduction, osteoconduction, and osteogenesis. Among all the available graft materials, only autogenous material possesses all three properties, whereas allografts, xenografts, and alloplastics generally exhibit only osteoconduction. However, allografts (demineralised freeze-dried bone) can also demonstrate osteoinduction (Nasr et al., 1999; Joshi et al., 2016).

Thus, the aim of this study is to evaluate the clinical and radiographic outcomes of different augmentation materials and surgical methods in alveolar ridge preservation procedures compared to natural post-extraction socket healing.

2 Methods

A literature search was conducted using the database PubMed/MEDLINE (National Library of Medicine). The research aim focused on the efficacy of various augmentation materials in alveolar ridge preservation compared to the natural healing of the extraction socket. Keywords and phrases were derived considering synonyms, related terms, and variations to cover a broad spectrum of relevant literature. These keywords included "alveolar ridge preservation," "alveolar bone grafting," "bone graft(s)," "bone remodelling," "extraction site management," "socket healing," and "socket preservation." Search queries were constructed using the identified keywords, and Boolean operators (AND, OR, NOT) were applied to combine or exclude terms. Filters for date ranges, article types, and other relevant criteria were also utilised.

The search resulted in 291 studies. The titles and abstracts of these studies were screened for relevance, excluding duplicates and clearly irrelevant studies. Full texts of potentially relevant articles were then reviewed to assess their suitability based on predefined criteria, such as study design, population, and outcomes measured.

A supplementary manual search was conducted by examining the references of the selected articles to identify additional relevant studies, ensuring no important literature was missed and validating the comprehensiveness of the database searches.

The selected articles, identified through both manual and electronic searches, were meticulously evaluated based on their titles and abstracts to ensure they met specific inclusion criteria. These criteria mandated that the studies be either randomized controlled clinical trials or prospective and retrospective clinical studies. Additionally, the included studies were required to have a mean follow-up time of at least two months to ensure sufficient duration for observing outcomes.

Conversely, studies were excluded if they were conducted in vitro, as these do not provide the same level of evidence as clinical trials. Further, articles not published in English were excluded to maintain consistency in language comprehension and interpretation. Publications dated prior to 2010 were also excluded to ensure the relevance and currency of the research findings.

2.1 Statistics

Descriptive statistics, frequency analysis, and content analysis were employed as part of the qualitative methodology to systematically analyze the textual content of the included studies. It is important to note that, given the narrative nature of this study, regression analysis and meta-analysis techniques were not deemed suitable for the analytical framework.

3 Results

Among 291 studies, 228 studies were published within ten years, 67 studies were randomized clinical trials, only 19 studies were included in the study. Eighteen studies provided data on the clinical post-extraction dimensional changes of alveolar bone. Four studies reported using three-dimensional computed tomography to measure changes in alveolar bone dimensions. The characteristics of the included studies are presented in **Table 1**. Notably, all the included studies were randomized clinical trials (RCT) with follow-up periods ranging from 3 to 12 months, with only two studies having a follow-up period of less than three months (Temmerman et al., 2016; Areewong et al., 2019). Additionally, four studies did not use any grafting materials for alveolar ridge preservation procedures (Temmerman et al., 2016; Areewong et al., 2019; Hauser et al., 2013; Karaca et al., 2015), one of which used only autograft (Karaca et al., 2015), while the other three (Temmerman et al., 2016; Areewong et al., 2019; Hauser et al., 2013) utilized growth factors (PRF) for ridge preservation procedures.

Table 1. Characteristics of all selected studies.

Study	Design	F-up	Groups	Graft mat	Flap (Y/N)	Prim clo (Y/N)
Jung et al. 2013	RCT	6	T=10 C=10	AP	N	N
Kotsakis et al. 2014	RCT RCT RCT	5	T1=8 T2=10 C=10	AP	N	N
Madan et al. 2014	RCT	6	T=15 C=NA	AP	Mix	N
Mayer et al. 2016	RCT	4	T=20 C=20	AP	Y	Y
Spinato et al. 2014	RCT	4	T=19 C=12	AG	N	N
Temmerman et al. 2016	RCT	3	T=22 C=22	ATG (PRF)	N	N
Areewong et al. 2019	RCT	2	T=15 C=15	ATG (PRF)	N	N
Hauser et al. 2013	RCT	2	T1=9 T2=6 C=8	ATG (PRF)	Y	N
Barone et al. 2012	RCT	4	T=29 C=29	XG	N	N
Barone et al. 2016	RCT	3	T=30 C=30	XG	Y	Y
Barone et al. 2017	RCT	4	T=15 C=15	XG	Y	Y
Festa et al. 2011	RCT	6	T=15 C=15	XG	Y	Y
Siciliano et al. 2017	RCT	6	T=10 C=10	XG	Y	N
Cardaropoli et al. 2014	RCT	4	T=24 C=24	XG	N	N
Cardaropoli et al. 2015	RCT	12	T=24 C=24	XG	N	N
Pang et al. 2014	RCT	6	T1=15 T2=15 C1=15 C2=15	XG	Y	Y
Karaca et al. 2015	RCT	3	T=10 C=10	ATG	Y	N
Rasperini et al. 2010	RCT	3	T=7 C=9	XG	N	N

Notes: Study Year (Yr), Follow-up in months (F-up), Grafting materials (Graft mat), Alloplastic (AP), Allograft (AG), Autograft (ATG), Autograft (Platelet-Rich Fibrin) (ATG (PRF)), Xenograft (XG), Primary closure (Prim clo), Randomised Controlled Trial (RCT).

In terms of the materials used, alloplastic materials and xenografts were the most commonly used augmentation materials, being utilized in four (Jung et al., 2013; Kotsakis et al., 2014; Madan et al., 2014; Mayer et al., 2016) and nine studies (Barone et al., 2012, 2016, 2017; Cardaropoli et al., 2014, 2015; Festa et al., 2011; Pang et al., 2014; Siciliano et al., 2017), respectively. Additionally, Freeze-dried allograft (Spinato et al., 2014) and autogenous graft (Hauser et al., 2013) were each used in only one study. Furthermore, barrier membranes were utilised in 14 studies. Half of the selected studies raised a mucoperiosteal flap to perform ridge preservation surgeries (Barone et al., 2017; Festa et al., 2011; Hauser et al., 2013; Karaca et al., 2015; Madan et al., 2014; Mayer et al., 2016; Pang et al., 2014; Siciliano et al., 2017), while the remaining studies attempted to achieve primary closure.

Moving on to the types of biomaterials used in ARP procedures, different biomaterials were utilized in the 18 selected studies, classified into four main categories: autograft, allograft, alloplastic, and xenograft materials. Alveolar ridge preservation interventions documented in any of the study groups of the selected studies were grouped into seven treatment methods: (a) bovine bone particles (BBP) + socket sealing (SS), (b) bovine bone granules 90% and porcine collagen 10% (BBG/PC) + socket sealing (SS), (c) cortico-cancellous porcine bone particles (CPBP) + socket sealing (SS), (d) allograft particles (AG) + socket sealing (SS), (e) alloplastic material (AP) with or without SS, (f) autologous blood-derived products (ABDP), mainly platelet-rich fibrin (PRF), and (g) SS alone. All these different ARP procedure methods were compared to the control group (i.e., spontaneous socket healing after extraction). **Table 2** provides detailed information on the seven treatment modalities (Avila-Ortiz et al., 2019).

Table 2. Specific distribution of different treatment modalities.

Study	Xenograft BBP+SS	Xenograft BBG/PC+SS	Xenograft CPBP+SS	Allograft AG+SS	Alloplastic AP+SS	Autologous ABDP/PRF	SH SS alone
Jung et al., 2013		X			X		
Kotsakis et al., 2014	X				X		
Madan et al., 2014					X		
Mayer et al., 2016					X		
Spinato et al., 2014				X			
Temmerman et al., 2016						X	
Areewong et al., 2019						X	
Hauser et al., 2013						X	
Barone et al., 2012			X				
Barone et al., 2016			X				
Barone et al., 2017			X				
Festa et al., 2011			X				
Siciliano et al., 2017		X					
Cardaropoli et al., 2014	X						
Cardaropoli et al., 2015	X						
Pang et al., 2014	X						
Karaca et al., 2015							X
Rasperini et al., 2010		X					

Notes: Spontaneous healing (SH).

3.1 Bone changes in response to augmentation materials

Horizontal bone changes between control and test groups examined by clinical measurement were disclosed in 11 studies (Rasperini et al., 2010; Jung et al., 2013b; Hauser et al., 2013; Festa et al., 2013; Barone et al., 2013, 2017; Kotsakis et al., 2014; Cardaropoli et al., 2014, 2015; Madan et al., 2014; Iorio-Siciliano et al., 2017). Among these studies, all groups treated by the ARP procedure showed more favourable results than the control groups (mainly revealed in **Tables 3, 4**). Furthermore, different changes in vertical bone loss between control and test groups at the mid-buccal aspect were documented in all studies. For all these vertical parameters, groups treated with the ARP procedure achieved more favorable results than the control group except in one study in which there were no differences between the two groups in terms of mesial and distal height changes (Iorio-Siciliano et al., 2017).

3.1.1 ARP procedure with xenografts

Focusing on the ARP procedure with xenografts, there was evidence of the reduced amount of alveolar bone resorption when xenograft was utilised in the treatment. In the studies, alveolar sockets were augmented by bovine bone particles (BBP). Although the weighted values showed a positive effect after the surgery, there were no significant results compared to the control groups (spontaneous healing). Four studies illustrated in **Table 3** (Cardaropoli et al., 2014, 2015; Pang et al., 2014; Iorio-Siciliano et al., 2017) demonstrated that there was an inadequate sign of a difference between BBP + socket sealing (with porcine collagen membrane or sponge) and control, especially in the study carried out by Siciliano in 2017. The mesial bone had no changes between baseline (-0.0 ± 00) and follow-up (-0.0 ± 00); the same result was shown at the distal site in that study. At the buccal site, there was a significantly different outcome in the test group ($-0.3\,\text{mm} \pm 0.5\,\text{mm}$) compared to the control ($-1.1\,\text{mm} \pm 1.0\,\text{mm}$). The lingual palatal site reported a more favourable result in the test group, but it was not significant. Taking into consideration the horizontal bone loss, among these four studies, the test group showed better outcomes than the control sites, but the difference was not significant except in one study by Pang et al. (2014). There was dramatically higher horizontal bone loss ($-3.56\,\text{mm}$) in the control group compared to the experimental group ($-1.84\,\text{mm}$). No significant statistical difference was reported in the remaining three studies.

Table 3. Horizontal and Vertical bone changed between experimental and control groups when Xenograft was utilized in the ARP procedures.

<table>
<tr><th rowspan="2">Study</th><th rowspan="2">Obs time (m)</th><th rowspan="2">Surgical intervention materials</th><th colspan="3">Test group changes (mm)</th><th colspan="2">Control group changes (mm)</th></tr>
<tr><th colspan="2">Horizontal</th><th>Vertical</th><th>Horizontal</th><th>Vertical</th></tr>
<tr><td rowspan="6">Festa, 2011</td><td rowspan="6">3</td><td rowspan="6">CPBP+SS</td><td rowspan="5">Baseline</td><td rowspan="5">9.8 ± 1.2</td><td>MB: -0.6 ± 1.4</td><td rowspan="5">9.9 ± 1.0</td><td></td></tr>
<tr><td>ML: -0.5 ± 1.3</td><td>MB: -3.1 ± 1.3</td></tr>
<tr><td>M: -0.3 ± 0.8</td><td>ML: -2.4 ± 1.6</td></tr>
<tr><td>D: -0.4 ± 0.8</td><td>M: -0.4 ± 1.2</td></tr>
<tr><td></td><td>D: -0.5 ± 1.0</td></tr>
<tr><td>Follow-up</td><td>8.0 ± 1.1</td><td></td><td>6.2 ± 1.3</td><td></td></tr>
<tr><td rowspan="5">Siciliano, 2017</td><td rowspan="5">6</td><td rowspan="5">BBP+SS</td><td rowspan="3">Baseline</td><td rowspan="3">11.3 ± 2.0</td><td>M: -0.0 ± 0.0</td><td rowspan="3">12.6 ± 1.3</td><td>M: -0.0 ± 0.0</td></tr>
<tr><td>B: -0.3 ± 0.5</td><td>B: -1.1 ± 1.0</td></tr>
<tr><td>D: -0.1 ± 0.3</td><td>D: -0.1 ± 0.3</td></tr>
<tr><td rowspan="2">Follow-up</td><td></td><td>LP: -0.1 ± 0.3</td><td rowspan="2">9.8 ± 1.5</td><td>LP: -0.7 ± 0.7</td></tr>
<tr><td>9.7 ± 2.3</td><td></td><td></td></tr>
<tr><td rowspan="2">Cardaropoli, 2014</td><td rowspan="2">4</td><td rowspan="2">BBP+SS</td><td>Baseline</td><td>10.42 ± 1.82</td><td>4.21 ± 0.39</td><td>10.25 ± 1.57</td><td>4.23 ± 0.68</td></tr>
<tr><td>Follow-up</td><td>9.71 ± 2.12</td><td>4.77 ± 0.42</td><td>6.21 ± 1.56</td><td>5.90 ± 0.68</td></tr>
<tr><td>Pang, 2014</td><td>6</td><td>BBP+SS</td><td colspan="2">-1,84</td><td>-1,54</td><td>-3,56</td><td>-3,26</td></tr>
<tr><td rowspan="2">Cardaropoli, 2015</td><td rowspan="2">12</td><td rowspan="2">BBP+SS</td><td colspan="2" rowspan="2"></td><td>M: 0.31 ± 0.30</td><td rowspan="2"></td><td>M:0.33 ± 0.30</td></tr>
<tr><td>D: 0.35 ± 0.26</td><td>D: 0.38 ± 0.27</td></tr>
<tr><td rowspan="4">Barone 2012</td><td rowspan="4">4</td><td rowspan="4">CPBP +SS</td><td colspan="2" rowspan="4">1.6 ± 0.55</td><td>M: -0.3 ± 0.76</td><td rowspan="4">3.6 ± 0.72</td><td>M: -1.0 ± 0.7</td></tr>
<tr><td>B: -1.1 ± 0.96</td><td>B: -2.1 ± 1.6</td></tr>
<tr><td>D: -0.3 ± 0.85</td><td>D: -1 ± 0.8</td></tr>
<tr><td>L: -0.9 ± 0.98</td><td>L: -2 ± 0.73</td></tr>
<tr><td rowspan="2">Barone 2016</td><td rowspan="2">3</td><td rowspan="2">CPBP +SS</td><td colspan="2">T1: 1.33</td><td>T1: 0.3</td><td rowspan="2">3,6</td><td rowspan="2">2,1</td></tr>
<tr><td colspan="2">T2: 0.93</td><td>T2: 0.57</td></tr>
<tr><td rowspan="2">Barone 2017</td><td rowspan="2">4</td><td rowspan="2">CPBP +SS</td><td colspan="2" rowspan="2"></td><td>T1:22.8% ± 8.9%</td><td rowspan="2"></td><td rowspan="2">43.9% ± 4.7%</td></tr>
<tr><td>T2:24.3% ± 7.0%</td></tr>
</table>

Similarly, alveolar ridge procedures combined with cortico-cancellous porcine bone particles (CPBP) were reported in four studies. In 2001, Festa et al. demonstrated that at baseline, the ARP sites had a mean initial buccolingual/palatal width of 9.8 ± 1.2 mm, which decreased to 8.0 ± 1.1 mm after six months of healing, whereas the control sites ranged from an initial alveolar width of 9.9 ± 1.0 mm to 6.21 ± 1.3 mm ($p < .05$). Both test and control sites showed significant horizontal width reduction from baseline to final examination; however, significantly greater horizontal reabsorption was observed at control sites (3.7 ± 1.2 mm) compared with test sites (1.8 ± 1.3 mm) ($p < .05$).

Furthermore, Barone et al. published three studies in 2012, 2016, and 2017, respectively; CPBP+SS represented outstanding results at all aspects of different sites of alveolar ridge preservation. After four months of follow-up, vertical bone resorption was 0.3 ± 0.76 mm, 1.1 ± 0.96 mm, 0.3 ± 0.85 mm, 0.9 ± 0.98 mm at the buccal, lingual, mesial, and distal sites, respectively, at the test site. In contrast, vertically, bone loss at the control site showed larger values, two to three times greater than at the test sites (-1.0 ± 0.7 mm, -2.1 ± 1.6 mm, -1 ± 0.8 mm, -2 ± 0.8 mm at the buccal, lingual, mesial, and distal sites, respectively). Furthermore, changes in the horizontal dimension revealed an average bone loss of 1.6 ± 0.55 mm. In the non-grafted group, horizontal bone reduction was significantly higher (mean resorption 3.6 ± 0.72 mm).

Moreover, a study in 2016 presented dramatically positive results of CPBP in ARP procedures, showing nearly four times less bone resorption in the test group compared to the control group. There was no data showing horizontal bone loss in the 2017 study by Barone et al., but vertical bone loss in the experimental group showed significantly better outcomes than in the control group (Test: 23.55% mean bone loss, Control: 43.9%).

3.1.2 ARP procedure with alloplastic materials

The results carried out by Alloplastic material in ARP procedures were uneventful and showed more advantages in all aspects than the control groups. The mean changes in horizontal and vertical among all these studies were between 0.5 ± 2.45 mm, respectively.

In the study done by Madan et al. in 2014, for both the control and test groups, the mean value changes for crestal bone height after six months reported alveolar bone resorption at all aspects, except for mid-buccal (-1.28 ± 0.58 mm) and mid-lingual (-1.08 ± 0.64 mm) areas of the experiment group. In contrast, in the control group, resorption was extensively recognized at the mid-buccal area (2.45 ± 0.67 mm), in contrast to a mean value change in the test group of -1.28 ± 0.58 mm for the same sites after six months of follow-up. Moreover, at mesial-buccal and distal-buccal sites, the control group (1.85 ± 0.48 mm and 1.53 ± 0.54 mm, respectively) illustrated more bone resorption in alveolar ridge height compared with the experimental group (1.22 ± 0.47 mm and 1.33 ± 0.48 mm, respectively). Similarly, Beta-TCP showed more excellent results (Test: -0.9 mm Control: -2.0 mm) in the preservation of the vertical height compared to the control group in June's study 2013.

Additionally, another study done by Mayer in 2016 demonstrated the horizontal and vertical height at different levels (0, -3 mm and -6 mm). Significant alveolar ridge resorption was measured in the control group. Specifically, changes in horizontal ridge width were: -1.33 mm, -2.28 mm and -0.28 mm at 0 mm, -3 mm, and -6 mm, respectively. Contrary, in the test group, horizontal bone loss was observed much more stable, as showed in **Table 4**. Statistically significant differences in the horizontal dimensions (baseline to 4 months) were significant at all three points in the control group: At -3 mm, bone loss was -2.28 mm for the control with negligible bone gain (-0.03 mm) in the experimental group. At -6 mm, bone loss was -2.28 mm for control with negligible bone loss (0.035 mm) in the test group. Furthermore, the vertical distance (bone crest to the horizontal line connecting the CEJ of the neighbouring teeth) was similar among the two groups at baseline and were basically unchanged at the final re-entry measurements.

Interestingly, only one study performed full cone-beam computed tomography (CBCT) analysis, which was reported by Jung et al. in 2013. Measurements were taken at -1 mm,

Table 4. Difference between control and test groups in horizontal and vertical bone changes. MB: Mesial-buccal, MiB: Middle-buccal, DB: Distal-buccal, MiL: Middle-lingual.

Study	Obs time (m)	Surgical interventi on materials	Test group changes		Control group changes	
			Crestal height (baseline)	Crestal height (follow-up)	Crestal height (baseline)	Crestal height (follow-up)
Madan, 2014	6	AP+SS	MeB: 7.55 ± 0.90	MeB: 8.77 ± 0.6	MeB: 7.52 ± 0.80	MeB: 9.37 ± 0.91
			MiB: 8.40 ± 0.84	MiB: 7.12 ± 1.19	MiB: 8.15 ± 0.89	MiB: 10.60 ± 1.19
			DB: 8.03 ± 0.97	DB: 9.37 ± 1.15	DB: 7.74 ± 0.98	DB: 9.27 ± 1.02
			MiL: 6.62 ± 0.85	MiL: 5.53 ± 0.96	MiL: 6.68 ± 0.75	MiL: 6.68 ± 0.75
			Test group changes (mm)		**Control group changes (mm)**	
			Horizontal	**Vertical**	**Horizontal**	**Vertical**
Mayer, 2016	4	AP+SS	0 mm: -0.96 ± 2.63	5.04 ± 2.05	0 mm: -1.33 ± 2.25	5.54 ± 2.1
			-3mm: 0.03 ± 2.32		-3mm: -2.28 ± 2.336	
			-6mm: -0.035 ± 3.05	5.11 ± 2.70	-6mm: -0.28 ± 2.43	5.3 ± 1.6
Jung, 2013	6	Beta+TCP		-0,9		-.2.0
Kotsakis, 2014	5	AP+SS	-1,26	-0,48	-2,53	-1,12
Spirit, 2014	4	AP+SS	0,55	-0,27	-2,67	-1,17

−3 mm, and −5 mm according to the different thicknesses of the buccal bone plate. Three different types of ARP procedures were utilized (Beta-tricalcium phosphate, demineralized bovine bone matrix together with collagen matrix and demineralized bovine bone matrix with punch graft) to compare with the control group; data were described in **Table 5**.

Table 5. Changes in alveolar ridge width and height after 6month of follow-up based on CBCT measurements. B.H.: Height at mid-buccal, L.H.: Height of mid-lingual, H.W.: Horizontal width.

	Control	Beta-TCP	DBBM-C/CM	DBBM-C/PG
BHgraftC	NA	-3.9 ± 2.4	-1.5 ± 1.2	-0.5 ± 1.0
LHgraftC	NA	-3.5 ± 1.1	-1.3 ± 0.9	-0.5 ± 0.9
LHpalateC	-0.6 ± 0.6	-1.7 ± 0.6	-0.4 ± 1.4	0.3 ± 1.1
BHpalateC	-0.5 ± 0.9	-2 ± 2.4	0 ± 1.2	1.2 ± 2.9
HW-1C	-3.3 ± 2.0	-6.1 ± 2.5	-1.2 ± 0.8	-1.4 ± 1.0
HW-3C	-1.7 ± 0.8	-3.1 ± 1.6	-0.6 ± 0.6	-0.6 ± 0.5
HW-5C	-0.8 ± 0.5	-5.7 ± 3.0	-0.1 ± 0.2	-0.6 ± 0.9

Moreover, the mean height changes among all the test groups were between −0.4 mm to −3.9 mm. The differences were not statistically significant between the four groups except the group, which used Beta-TCP, bone loss at LHpalate (-1.7 ± 0.6 mm) and BHpalate (-2 ± 2.4 mm) was significantly higher than the control group.

The mean ridge width changes at the three levels below the crest (HW-1C, HW-3C, HW-5C) amounted to −3.3 mm, −1.7 mm, −0.8 mm for control sites. At all three levels, DBBM-C/CM and DBBM-C/PG were not significantly different; however, the study group that used Beta-TCP showed a significant inferior result at all aspects compared to the control group.

3.1.3 ARP procedure with autologous growth factor (Platelet-Rich Fibrin)

Turning to the ARP procedure with autologous growth factor (Platelet Rich Fibrin), PRF was introduced by Choukroun et al. in an early time (Dohan et al., 2006). It forms a three-dimensional network rich in various growth factors. Remarkably, all three studies utilizing

PRF demonstrated superior results compared to control groups (**Table 6**). Particularly, the study by Hauser et al. in 2013 showed a seven-fold reduction in bone resorption at the horizontal site in the test group (−0.48%) compared to the control group (−3.68%). A similar significant difference was observed at the buccal site, where the test group showed only a −0.1 mm loss, whereas the control group recorded −1.6 mm. Conversely, no statistically significant difference was found in the study by Areewong et al. in 2019, where both the control and test sites exhibited similar new bone formation after the ARP procedure (socket filled with PRF).

Table 6. ARP procedures utilizing autologous growth factor (PRF). M: Mesial, D: Distal, B: Buccal, L: Lingual.

Study	Obs time (m)	Surgical intervention materials	Test group changes (mm)		Control group changes (mm)	
			Horizontal	Vertical	Horizontal	Vertical
Temmerman, 2014	3	PRF	1mm: -2.4 ± 2.3	B: -0.1 ± 1.6	1mm: -5.4 ± 4.4	B: -1.6 ± 1.2
			3mm: -0.6 ± 0.7	L: -0.3 ± 1.2	3mm: -1.2 ± 1.1	L: -0.7 ± 0.8
			5mm: -0.4 ± 0.5		5mm: -0.5 ± 0.5	
Areewong, 2019	2	PRF	31.33% ± 18% new bone formation		26.33% ± 19.63 new bone formation	
Hauser, 2013	2	PRF	-0,48 %	M: -1.21 ± 0.40	-3,68 %	M: -0.77 ± 0.17
				D: -0.76 ± 0.25		D: 2.07 ± 0.81

3.1.4 ARP procedure with socket sealing (S.S.) alone

Considering the ARP procedure with Socket Sealing (S.S.) alone, among all selected studies (**Table 7**), only one study reported the ARP procedure using Socket Sealing alone. In the control group, the mean dimensional change in the height of the buccal crest was −1.03 mm (range −5.34 to −0.16 mm), and in the height of the lingual crest was −0.56 mm (range −3.2 mm to 1.25 mm) after three months of follow-up. Intra-group differences between the values at the initial phase and at three months were statistically significant.

Table 7. ARP procedures performed with S.S. (socket sealing) alone with autograft (FGG). V: Vertical, H: Horizontal.

	Control group (mm)		Test group (mm)	
	Baseline	Follow-up	Baseline	Follow-up
V-Buccal	7,26	5,98	6,98	7,31
V-Lingual	6,96	5,84	6,61	7,14
H-Buccal	3,76	2,62	3,96	2,85
H-Lingual	3,53	3,23	3,5	3,06

The mean dimensional change in the width of the buccal crest was −1.22 mm (range −1.68 mm to −0.41 mm), and in the width of the lingual crest was −0.24 mm (range −1.33 mm to 0.14 mm). In contrast, in the experimental group, the mean dimensional change in the height of the buccal crest was +0.06 mm (range −2.27 mm to 1.66 mm), and in the height of the lingual crest was +0.25 mm (range −1.62 mm to 1.65 mm). Significant differences were noted between the values at baseline and at three months. The mean dimensional change in the width of the buccal crest was −0.99 mm (range −2.71 mm to −0.20 mm), and in the width of the lingual crest was -0.59 mm (range -1.6 mm to 0.72 mm). Intra-group differences between the values at baseline and at three months were statistically significant.

3.1.5 ARP procedure with allograft material

Finally, regarding the ARP procedure with Allograft material, only one study from the selected literature reported ARP with allograft. Naturally healed sockets lost slightly more palatal height than treated sockets in both buccal bone thicknesses (BBT) ≤ 1 mm and > 1 mm, but without statistical significance. However, the differences in buccal height for BBT ≤ 1 mm (TG 0.27 mm and CG 1.17 mm) and in width for both BBT (≤ 1 mm – TG 0.55 mm and CG 2.67 mm, > 1 mm – TG 0.12 mm and CG 1.17 mm) were statistically significant (**Table 8**), except for buccal height in BBT > 1 mm (TG -0.38 mm and CG -0.5 mm).

Table 8. Height and width variation compare to the different buccal bone thickness. BBT: Buccal Bone Thickness, B-H: Buccal height, P-HL: Palatal-height, W: Width.

	Control group (mm)		Test group (mm)	
	Baseline	**Follow-up**	**Baseline**	**Follow-up**
V-Buccal	7,26	5,98	6,98	7,31
V-Lingual	6,96	5,84	6,61	7,14
H-Buccal	3,76	2,62	3,96	2,85
H-Lingual	3,53	3,23	3,5	3,06

4 Discussion

The procedure performed immediately after tooth extraction for the purpose of preserving the alveolar ridge volume within the bony envelope is called alveolar ridge preservation (ARP) (Karaca et al., 2015). Recent systematic reviews have recommended that alveolar ridge preservation procedures are effective in reducing the dimensional alteration, mainly horizontal and vertical, after tooth extraction (Horowitz et al., 2012; Vittorini Orgeas et al., 2013). However, none of the published articles in terms of ARP techniques can ultimately preserve the alveolar ridge contour.

Hard tissue loss. The present study assessed the effectiveness of alveolar ridge preservation procedures followed by tooth extraction of single and multiple root teeth when delayed implant or delivery of fixed dental prosstudy is intended. Additionally, the effects of relevant clinical factors that may affect the outcome of ARP procedures were explored with different augmentation biomaterials. The results of the study have established that although ARP procedures do not prevent hard tissue dimensional loss after extraction, these procedures play a dramatic role in reducing alveolar bone resorption after tooth extraction (Vignoletti et al., 2012; Avila-Ortiz et al., 2014b; Willenbacher et al., 2016; MacBeth et al., 2017).

Furthermore, the present study focused on the outcomes of ARP procedures augmented with different materials in respect of hard tissue dimensional resorption after tooth extraction. Although the primary goal of alveolar ridge preservation procedures is to minimize the alveolar bone loss after a tooth extraction, the clinical significance of this dimensional loss might be varied according to the allocation of the tooth in the jaws. For instance, where two millimeters of bone loss vertically in the anterior zone of the maxilla may result in a more clinically challenging situation compared with 2 mm vertical bone loss in the posterior maxilla or anterior mandible. Accordingly, it is important also to assess end-point clinical outcomes such as the outcome of implant therapy after these procedures or the need for further grafting before implant placement as well as patient-centered outcomes. Also, it is almost impossible to estimate the outcome of ARP procedures in the present study according to the location of the teeth because many studies did not include detailed information on the situation of the admitted extraction sockets. Hard tissue dimensional resorption may also affect by the location of the teeth after extraction, as the thickness of buccal bone is varied depending on the different tooth allocation. Hence, future studies should focus on the comparison of the effectiveness of ARP procedures when it is performed for the extraction sockets in anterior areas with that of posterior positions (MacBeth et al., 2017; Bassir et al., 2018).

Effect of local and systemic factors. In addition to buccal bone thickness, the impact of other local and systemic factors on clinical outcomes could not be assessed thoroughly. This limitation arises from either inadequate data reporting or substantial divergence in study methodologies among the selected randomized clinical trials. For instance, the influence of prior history of periodontitis could not be evaluated due to its absence from the documentation in any of the reviewed articles. Similarly, quantitative analysis of variables other than buccal bone thickness was not feasible based on the available evidence. The effect of smoking did not appear to significantly affect the results across the included studies, as the inclusion criteria allowed for an equal distribution of smokers among treatment groups (Thalmair et al., 2013; Barone et al., 2017; Guarnieri et al., 2017).

Effect of socket anatomy. Regarding the unique anatomy of alveolar sockets, out of the 19 randomized clinical trials reviewed, a total of eight studies included a combination of single- and multi-rooted teeth (Barone et al., 2012; Temmerman et al., 2014; Barone et al., 2017; Cardaropoli et al., 2012, 2014, 2015; Iorio-Siciliano et al., 2017; Kotsakis et al., 2014; Rasperini et al., 2010; Mayer et al., 2016). While none of these studies specifically aimed to assess differences in ARP procedure outcomes based on anatomical features of extraction sites (e.g., single- vs. multi-rooted), the current evidence suggests this factor does not significantly impact outcomes (Walker et al., 2017). However, a relevant study concluded that extraction of multiple neighbouring teeth during a single session may lead to more pronounced alveolar bone resorption, attributed to inadequate interdental blood supply to the extraction sockets (Al-Hezaimi et al., 2011).

Effect of primary closure. Among the included studies showed that the weighted benefit of alveolar ridge preservation procedures presented more advanced results when primary closure was achieved. However, the variability among the studies included in the analysis, such as different types of socket anatomy, location of the socket, grafting materials, and type of membrane, make it difficult to make a definitive conclusion about the impact of primary closure on the spatial changes of the alveolar ridge. In addition, achieving primary closure may not only play a negative effect on the soft tissue outcomes of alveolar ridge preservation by altering the location of the mucogingival junction but also, it may lead to suboptimal esthetic results and additional surgical trauma, which both may affect patient-centred outcomes of alveolar ridge preservation. According to the previously published clinical studies

(Engler-Hamm et al. 2011; Kim et al. 2013) and one systematic review (Avila-Ortiz et al. 2014b), undertaking primary closure following flap elevation did not present to provide an additional benefit in connection with alveolar ridge preservation (Fiorellini et al. 2005; Pelegrine et al. 2010; Festa et al. 2013; Pang et al. 2014).

Effect of graft. Utilizing of free gingiva graft (FGG) for ARP procedure found in one study only, the evaluation was taken after three months of healing, there was a crestal bone lost height at buccal and lingual aspect (-1.03 ± 0.00 mm and -0.56 ± 0.00 mm, respectively) of the alveolar sockets in the control group was founded, whereas the test sites that were covered with the free gingival graft had gained crestal bone height at the buccal and lingual site ($+0.06 \pm 0.00$ mm and $+0.25 \pm 0.00$ mm, respectively) this was a statistical difference between the two groups. In light of the result of this study, it can be determined that covering the extraction socket with FGG is sufficient to preserve the height of the buccal and lingual crestal bone. However, this technique was found to be insufficient in avoiding tissue shrinkage and partial necrotizing.

Additionally, quantitatively analyze the general studies disclosed that ARP-SG using a bone substitute (i.e., xenogenic material with S.S., alloplastic material, allograft with socket sealing or with or without socket sealing) was apparently admirable to the control group in the matter of preservation of horizontal bone width, mid-buccal bone height, and mid-lingual bone height, measured clinically (Vignoletti et al. 2012; Vittorini Orgeas et al. 2013; Avila-Ortiz et al. 2014b; Atieh et al. 2015; Willenbacher et al. 2016; MacBeth et al. 2017; Troiano et al. 2018).

Added effects – barrier membrane and PRF. Barrier membranes are frequently utilized in the ARP procedure to maintain a sealed environment that facilitates regeneration underneath, based on the theory of Guided Bone Regeneration (GBR). The barrier membranes serve to inhibit the apical growth of epithelial cells from penetrating into the defect area, thereby allowing uneventful regeneration under the membrane (Melcher, 1976).

Two studies have illustrated the benefits of utilizing barrier membranes in ARP procedures. Leković and his colleagues (1997) demonstrated in their study the use of nonabsorbable membranes, specifically Polytetrafluoroethylene (ePTFE), in preserving the alveolar ridge after tooth extraction. Measurements taken after six months showed no clinical changes in the test group (± standard deviation), whereas significant volumetric changes were observed in the control group.

In another study, Pinho and his team (2006) evaluated titanium membranes combined with or without autografts, finding no significant differences between groups. Their conclusion emphasized the importance of space maintenance over the choice of grafting materials in ARP procedures.

Moreover, Leković et al. (1998) highlighted the distinct mechanism of action of titanium membranes (non-resorbable) compared to resorbable membranes, emphasizing their effectiveness in minimizing membrane exposure and potentially avoiding secondary surgeries.

Bone regeneration was generally observed in the first few weeks, followed by the wound healing process. Approximately two months after tooth extraction, the woven bone could be noticed clearly. Moreover, according to the study done by Choukroun et al. (2006), the team used PRF as a graft material to fill the defect cavity after extraction. After two months of follow-up, the defect area was filled with bone totally. (Dohan et al., 2006) However, the other study by Girish and his co-workers (2013) observed that there was no statistically significant difference between the control group and the test group (PRF), while the study by Alzahrani et al. (Year) concluded that dimensional change of alveolar ridge in the group filled with PRF was statistically lesser than the control group, this result was monitored by the cast analysed and radiographic analysis.

Additionally, radiographic measurements revealed that the bone volume was more prominent in the test group (PRF) than in the control group (Girish Rao et al., 2013). In addition, it was found that alveolar ridge preservation procedure utilizing platelet-rich fibrin alone provide a significant positive benefit with regard to hard tissue dimensional changes in horizontal, vertical, buccal, lingual, mesial and distal aspects. It was also found that the mean difference in horizontal dimensional changes of hard tissue between ARP procedures and control sites was almost seven times different when alveolar ridge preservation procedures were performed using platelet-rich fibrin. It should be mentioned that this analysis was reported a similar result in the study by Temmerman in 2014, that data for the application of platelet-rich fibrin for alveolar ridge preservation presents outstanding outcomes in all aspects than the control group. (Hauser et al., 2013; Madan et al., 2014; Areewong et al., 2019).

The increased frequency of utilizing PRF was found nowadays in daily dental practice, although the advantage of using PRF is still controversial. Therefore, future clinical studies are required more to justify the clinical benefits of utilization of platelet-rich fibrin for alveolar ridge preservation procedures.

Effect of surgical techniques on ARP. Bone remodelling or formation within the alveolar socket is a natural phenomenon after extraction, but it will occur only if the bony wall remains intact within the alveolar ridge. Several surgical techniques have been introduced to minimize the bone loss of the alveolar ridge to an acceptable level after tooth extraction (Fickl et al., 2008a). Studies have shown that minimally invasive tooth extraction and flap elevation are crucial for the success of these procedures.

Human maxillary and mandibular structures are composed of specific anatomical elements with appropriate composition, function, and physiology: basal bone, alveolar process, and bundle bone. The bundle bone lines all over the alveolar sockets and extends superiorly, forming the crest of the buccal bone (Fickl et al., 2008a, 2008b; Blanco et al., 2008; Caneva et al., 2010; Vignoletti et al., 2012; Araújo et al., 2015).

The bundle bone is the first type of bone to be resorbed after tooth extraction (Boyne, 1966; Devlin & Sloan, 2002). Studies reported that the rate of alveolar ridge resorption is faster six months after tooth extraction (Pietrokovski & Massler, 1967a; Johnson, 1969), continuing at an average of 0.5% to 1.0% per year throughout life (Carlsson & Persson, 1967; Ashman, 2000a). Results showed that socket height would never reach its original coronal level after healing, while horizontal resorption was found to be more severe in the posterior region compared to the premolar region (Schropp et al., 2003a; Hämmerle et al., 2012). However, there was a tendency for more palatal bone resorption compared to buccal, and more vertical than horizontal resorption during the remodelling process (Pietrokovski & Massler, 1967a, 1967b).

Studies from other research centres showed that bone resorption occurred in two phases (see Figure 1). Bundle bone was rapidly resorbed and replaced by woven bone during the first phase, resulting in significant reduction in bone height, especially at the buccal site of the alveolar socket, where the crestal portion is composed only of bundle bone (Araújo & Lindhe, 2005). Based on studies, buccal bone undergoes more resorption due to its thin anatomical morphology, resulting in 0.8 mm and 1.1 mm of bone resorption in the anterior and premolar sites, respectively (Huynh-Ba et al., 2010).

Animal studies have investigated the osteogenic potential of periodontal ligament-derived cells. Cardaropoli et al. (2005) demonstrated minimal influence on socket healing features after three months. During the subsequent phase, remodelling of the alveolar bone's outer surface resulted in horizontal and vertical changes, although this finding remains controversial. Several studies have documented that insufficient blood supply and local inflammation may lead to bone resorption. However, bone remodelling involves complex factors—physiological, functional, and structural. Surgical trauma from the extraction site activates microtrauma or damage to the surrounding bony surface, thereby accelerating the bone remodelling process (Garetto et al., 1995).

Statistically, Schropp et al. (2003) revealed that two-thirds of soft and hard tissue changes were observed within the first three months. A twelve-month follow-up reported 50% (6.1 mm) crestal bone width resorption, with 60% occurring in the initial three months (3.8 mm) (Schropp et al., 2003). A recent systematic review indicated greater bone reduction horizontally (3.79 mm, corresponding to 29–63%) than vertically (1.24 mm, corresponding to 11–22%) during the first 24 weeks. However, other long-term studies reported 40–40% reduction in bone height and width (Ashman, 2000a, b). Flap elevation during tooth extraction was shown to cause short-term alveolar ridge changes, with no detectable differences reported in long-term follow-ups (Caneva et al., 2010; Tan et al., 2012).

Study limitations. All study designs with a control or comparison, including RCTs and controlled clinical trials with parallel-group or split-mouth designs, were included in order to present all existing evidence on the effectiveness of alveolar ridge preservation. Most of the selected studies performed separate analyses for clinical and radiographic data. This can be regarded as one of the strengths of those studies since it has been shown that radiographic measurements underestimate alveolar bone dimensional loss compared to the measures taken during the surgery. Hence, it may not be appropriate to gather clinical and radiographic data together. Besides, it should be emphasized that the radiographic measurements of alveolar ridge dimensions may not indicate the accurate ridge dimensions since it is impossible to measure and differentiate the new bone formation from the remaining graft particles on radiographs. Hence, the outcomes of radiographic analyses should be taken with caution (Lascala et al., 2004; Grimard et al., 2009; Serino et al., 2017).

One more remarkable piece of information is that none of the selected studies includes the histologic and histomorphometry results. Although relevant to obtain further awareness on the biological characteristics of newly formed tissue following the utilization of different biomaterials (Barone et al., 2013; Barallat et al., 2014; Corbella et al., 2017), there was not much information to assess the effect of ARP procedure as an approach that is aimed initially at diminishing the alveolar ridge resorption after tooth extraction to expedite implant delivering and to enhance implant and patient-reported outcomes (Bassir et al., 2018; Avila-Ortiz et al., 2019).

Overall, significant heterogeneity was discovered in the analysis of the outcome variable from the selected studies. Due to the broad definition of alveolar ridge preservation, this is the main reason causing this heterogeneity, which includes any surgical procedures to preserve the alveolar ridge dimension after tooth extraction. Hence, these procedures may be performed with or without the use of resorbable or non-resorbable barrier membranes, with or without the use of various grafting materials, with or without the use of growth factors, or any of these combinations. Moreover, any of these procedures can be done with or without raising a mucoperiosteal flap as well as with or without achieving a primary closure. Furthermore, studies that focus on inspecting the clinical outcomes of ARP procedures may include intact or damaged extraction sockets in the anterior or posterior maxilla or mandible. The presence of all these variables results in hundreds of methods of performing and studying alveolar ridge preservation procedures. These variabilities introduce a challenge for all clinical studies evaluating the effectiveness of alveolar ridge procedures, as the clinical studies on this topic are heterogeneous in nature. One option to address this challenge is only to include the studies that performed alveolar ridge procedures using one specific biomaterial with a particular technique for extraction sites in the exact locations and with similar morphology. This strategy would perhaps reduce the heterogeneity among the included studies (Thalmair et al., 2013; Barone et al., 2017; Guarnieri et al., 2017).

Conclusions

In conclusion, alveolar ridge preservation (ARP) procedures are definitively more effective than natural healing in reducing post-extraction bone resorption, ensuring better preservation of both horizontal and vertical bone dimensions. The effectiveness of ARP is significantly influenced by the choice of grafting materials and surgical techniques. Corticocancellous porcine bone particles (CPBP) and alloplastic materials have demonstrated superior results, consistently outperforming control groups in maintaining alveolar ridge dimensions. Platelet-rich fibrin (PRF) has also shown a remarkable ability to reduce bone resorption and promote bone preservation.

Furthermore, the use of barrier membranes in ARP procedures provides additional support, enhancing the preservation outcomes. While autografts possess comprehensive regenerative properties, xenografts and allografts also offer substantial benefits, making them valuable alternatives in clinical practice.

For optimal clinical outcomes, future research should focus on refining ARP techniques and materials, emphasizing long-term effectiveness and practicality. Studies should explore the cost-effectiveness and ease of application to facilitate broader implementation of these procedures. By adopting tailored ARP strategies based on specific clinical scenarios and patient needs, dental professionals can ensure improved long-term success of dental restorations, thereby sustaining health, function, and aesthetics for patients.

Acknowledgements

The authors would like to thank Professor Dr. med. dent. Thomas Stamm for his assistance in ensuring that the manuscript complies with the journal's format standards. We appreciate his commitment and support throughout the submission process.

Ethical approval

No ethical approval was required for this study as it did not involve human participants, animal subjects, or sensitive data. This study falls under the category of data collection without participant identification.

Consent for publication

Not applicable.

Authors' contributions

The author(s) declare that all the criteria for authorship designated by the International Committee of Medical Journal Editors have been met. More specifically, these are: (a) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (b) Drafting the work or revising it critically for important intellectual content; AND (c) Final approval of the version to be published; AND (d) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interests

The author(s) declare that there are no competing interests related to this work.

Author notes

Correspondence concerning this article should be addressed to Dr. Li Xinda, Department of Periodontology, Semmelweis University, Szentkirályi utca 47, 1088 Budapest, Hungary.
e-mail: dr.li.dmd@outlook.com

References

Al-Hezaimi, K., Levi, P., Rudy, R., Al-Jandan, B., & Al-Rasheed, A. (2011). An extraction socket classification developed using analysis of the bone type and blood supply to the buccal bone in monkeys. *The International Journal of Periodontics & Restorative Dentistry, 31*, 421–427.

Amler, M.H. (1969). The time sequence of tissue regeneration in human extraction wounds. *Oral Surgery, Oral Medicine, and Oral Pathology, 27*, 309–318.

Amler, M.H., Johnson, P.L., & Salman, I. (1960). Histological and histochemical investigation of human alveolar socket healing in undisturbed extraction wounds. *Journal of the American Dental Association (1939), 61*, 32–44.

Araújo, M.G., & Lindhe, J. (2005). Dimensional ridge alterations following tooth extraction. An experimental study in the dog. *Journal of Clinical Periodontology, 32*, 212–218.

Araújo, M.G., da Silva, J.C.C., de Mendonça, A.F., & Lindhe, J. (2015). Ridge alterations following grafting of fresh extraction sockets in man. A randomized clinical trial. *Clinical Oral Implants Research, 26*, 407–412.

Areewong, K., Chantaramungkorn, M., & Khongkhunthian, P. (2019). Platelet-rich fibrin to preserve alveolar bone sockets following tooth extraction: A randomized controlled trial. *Clinical Implant Dentistry and Related Research, 21*, 1156–1163.

Ashman, A. (2000a). Postextraction ridge preservation using a synthetic alloplastic. *Implant Dentistry, 9*, 168–176.

Ashman, A. (2000b). Ridge preservation: important buzzwords in dentistry. *General Dentistry, 48*, 304–312.

Atieh, M.A., Alsabeeha, N.H.M., Payne, A.G.T., Duncan, W., Faggion, C.M., & Esposito, M. (2015). Interventions for replacing missing teeth: alveolar ridge preservation techniques for dental implant site development. *The Cochrane Database of Systematic Reviews, CD010176.*

Atwood, D.A. (1971). Reduction of residual ridges: a major oral disease entity. *The Journal of Prosthetic Dentistry, 26*, 266–279.

Avila-Ortiz, G., Chambrone, L., & Vignoletti, F. (2019). Effect of alveolar ridge preservation interventions following tooth extraction: A systematic review and meta-analysis. *Journal of Clinical Periodontology, 46*(Suppl 21), 195–223.

Avila-Ortiz, G., Elangovan, S., Kramer, K.W.O., Blanchette, D., & Dawson, D.V. (2014a). Effect of alveolar ridge preservation after tooth extraction: a systematic review and meta-analysis. *Journal of Dental Research, 93*, 950–958.

Avila-Ortiz, G., Rodriguez, J.C., Rudek, I., Benavides, E., Rios, H., & Wang, H.-L. (2014b). Effectiveness of three different alveolar ridge preservation techniques: a pilot randomized controlled trial. *The International Journal of Periodontics & Restorative Dentistry, 34*, 509–521.

Barallat, L., Ruíz-Magaz, V., Levi, P.A., Mareque-Bueno, S., Galindo-Moreno, P., & Nart, J. (2014). Histomorphometric results in ridge preservation procedures comparing various graft materials in extraction sockets with non-grafted sockets in humans: a systematic review. *Implant Dentistry, 23*, 539–554.

Barone, A., Ricci, M., Tonelli, P., Santini, S., & Covani, U. (2013). Tissue changes of extraction sockets in humans: a comparison of spontaneous healing vs ridge preservation with secondary soft tissue healing. *Clinical Oral Implants Research, 24*, 1231–1237.

Barone, A., Toti, P., Quaranta, A., Alfonsi, F., Cucchi, A., Negri, B., Di Felice, R., Marchionni, S., Calvo-Guirado, J.L., Covani, U., & Nannmark, U. (2017). Clinical and Histological changes after ridge preservation with two xenografts: preliminary results from a multicentre randomized controlled clinical trial. *Journal of Clinical Periodontology, 44*, 204–214.

Bassir, S.H., Alhareky, M., Wangsrimongkol, B., Jia, Y., & Karimbux, N. (2018). Systematic Review and Meta-Analysis of Hard Tissue Outcomes of Alveolar Ridge Preservation. *The International Journal of Oral & Maxillofacial Implants, 33*, 979–994.

Blanco, J., Nuñez, V., Aracil, L., Muñoz, F., & Ramos, I. (2008). Ridge alterations following immediate implant placement in the dog: flap versus flapless surgery. *Journal of Clinical Periodontology, 35*, 640–648.

Boyne, P.J. (1966). Osseous repair of the postextraction alveolus in man. *Oral Surgery, Oral Medicine, and Oral Pathology, 21*, 805–813.

Caneva, M., Botticelli, D., Salata, L.A., Souza, S.L.S., Bressan, E., & Lang, N.P. (2010). Flap vs ”flapless” surgical approach at immediate implants: a histomorphometric study in dogs. *Clinical Oral Implants Research, 21*, 1314–1319.

Cardaropoli, D., Tamagnone, L., Roffredo, A., & Gaveglio, L. (2015). Evaluation of Dental Implants Placed in Preserved and Nonpreserved Postextraction Ridges: A 12-Month Postloading Study. *The International Journal of Periodontics & Restorative Dentistry, 35*, 677–685.

Cardaropoli, D., Tamagnone, L., Roffredo, A., & Gaveglio, L. (2014). Relationship between the buccal bone plate thickness and the healing of postextraction sockets with/without ridge preservation. *The International Journal of Periodontics & Restorative Dentistry, 34*, 211–217.

Cardaropoli, G., Araújo, M., Hayacibara, R., Sukekava, F., & Lindhe, J. (2005). Healing of extraction sockets and surgically produced - augmented and non-augmented - defects in the alveolar ridge. An experimental study in the dog. *Journal of Clinical Periodontology, 32*, 435–440.

Carlsson, G.E., & Persson, G. (1967). Morphologic changes of the mandible after extraction and wearing of dentures. A longitudinal, clinical, and X-ray cephalometric study covering five years. *Odontologisk Revy, 18*, 27–54.

Chen, S.T., & Buser, D. (2009). Clinical and esthetic outcomes of implants placed in postextraction sites. *The International Journal of Oral & Maxillofacial Implants, 24*(Suppl), 186–217.

Corbella, S., Taschieri, S., Francetti, L., Weinstein, R., & Del Fabbro, M. (2017). Histomorphometric Results After Postextraction Socket Healing with Different Biomaterials: A Systematic Review of the Literature and Meta-Analysis. *The International Journal of Oral & Maxillofacial Implants, 32*, 1001–1017.

Darby, I., Chen, S.T., & Buser, D. (2009). Ridge preservation techniques for implant therapy. *The International Journal of Oral & Maxillofacial Implants, 24*(Suppl), 260–271.

Devlin, H., & Sloan, P. (2002). Early bone healing events in the human extraction socket. *International Journal of Oral and Maxillofacial Surgery, 31*, 641–645.

Dohan, D.M., Choukroun, J., Diss, A., Dohan, S.L., Dohan, A.J.J., Mouhyi, J., & Gogly, B. (2006). Platelet-rich fibrin (PRF): a second-generation platelet concentrate. Part I: technological concepts and evolution. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontics, 101*, e37–44.

Engler-Hamm, D., Cheung, W.S., Yen, A., Stark, P.C., & Griffin, T. (2011). Ridge preservation using a composite bone graft and a bioabsorbable membrane with and without primary wound closure: a comparative clinical trial. *Journal of Periodontology, 82*, 377–387.

Festa, V. M., Addabbo, F., Laino, L., Femiano, F., & Rullo, R. (2013). Porcine-derived xenograft combined with a soft cortical membrane versus extraction alone for implant site development: A clinical study in humans. *Clinical Implant Dentistry and Related Research, 15*(6), 707–713.

Fickle, S., Zuhr, O., Wachtel, H., Bolz, W., & Huerzeler, M. (2008a). Tissue alterations after tooth extraction with and without surgical trauma: A volumetric study in the beagle dog. *Journal of Clinical Periodontology, 35*(4), 356–363.

Fickl, S., Zuhr, O., Wachtel, H., Bolz, W., & Huerzeler, M. B. (2008b). Hard tissue alterations after socket preservation: An experimental study in the beagle dog. *Clinical Oral Implants Research, 19*(11), 1111–1118.

Fiorellini, J. P., Howell, T. H., Cochran, D., Malmquist, J., Lilly, L. C., Spagnoli, D., Toljanic, J., Jones, A., & Nevins, M. (2005). Randomized study evaluating recombinant human bone morphogenetic protein-2 for extraction socket augmentation. *Journal of Periodontology, 76*(4), 605–613.

Garetto, L. P., Chen, J., Parr, J. A., & Roberts, W. E. (1995). Remodeling dynamics of bone supporting rigidly fixed titanium implants: A histomorphometric comparison in four species including humans. *Implant Dentistry, 4*(3), 235–243.

Gerritsen, A. E., Allen, P. F., Witter, D. J., Bronkhorst, E. M., & Creugers, N. H. J. (2010). Tooth loss and oral health-related quality of life: A systematic review and meta-analysis. *Health and Quality of Life Outcomes, 8*, 126.

Girish Rao, S., Bhat, P., Nagesh, K. S., Rao, G. H. R., Mirle, B., Kharbhari, L., & Gangaprasad, B. (2013). Bone regeneration in extraction sockets with autologous platelet rich fibrin gel. *Journal of Maxillofacial & Oral Surgery, 12*(1), 11–16.

Grimard, B. A., Hoidal, M. J., Mills, M. P., Mellonig, J. T., Nummikoski, P. V., & Mealey, B. L. (2009). Comparison of clinical, periapical radiograph, and cone-beam volume tomography measurement techniques for assessing bone level changes following regenerative periodontal therapy. *Journal of Periodontology, 80*(1), 48–55.

Guarnieri, R., Stefanelli, L., De Angelis, F., Mencio, F., Pompa, G., & Di Carlo, S. (2017). Extraction socket preservation using porcine-derived collagen membrane alone or associated with porcine-derived bone: Clinical results of randomized controlled study. *Journal of Oral & Maxillofacial Research, 8*(1), e5.

Hämmerle, C. H. F., Araújo, M. G., Simion, M., & Osteology Consensus Group 2011. (2012). Evidence-based knowledge on the biology and treatment of extraction sockets. *Clinical Oral Implants Research, 23*(Suppl 5), 80–82.

Hauser, F., Gaydarov, N., Badoud, I., Vazquez, L., Bernard, J.-P., & Ammann, P. (2013). Clinical and histological evaluation of postextraction platelet-rich fibrin socket filling: A prospective randomized controlled study. *Implant Dentistry, 22*(3), 295–303.

Horowitz, R., Holtzclaw, D., & Rosen, P. S. (2012). A review on alveolar ridge preservation following tooth extraction. *The Journal of Evidence-Based Dental Practice, 12*(3), 149–160.

Horváth, A., Mardas, N., Mezzomo, L. A., Needleman, I. G., & Donos, N. (2013). Alveolar ridge preservation: A systematic review. *Clinical Oral Investigations, 17*(2), 341–363.

Huynh-Ba, G., Pjetursson, B. E., Sanz, M., Cecchinato, D., Ferrus, J., Lindhe, J., & Lang, N. P. (2010). Analysis of the socket bone wall dimensions in the upper maxilla in relation to immediate implant placement. *Clinical Oral Implants Research, 21*(1), 37–42.

Iasella, J. M., Greenwell, H., Miller, R. L., Hill, M., Drisko, C., Bohra, A. A., & Scheetz, J. P. (2003). Ridge preservation with freeze-dried bone allograft and a collagen membrane compared to extraction alone for implant site development: A clinical and histologic study in humans. *Journal of Periodontology, 74*(7), 990–999.

Iorio-Siciliano, V., Blasi, A., Nicolò, M., Iorio-Siciliano, A., Riccitiello, F., & Ramaglia, L. (2017). Clinical outcomes of socket preservation using bovine-derived xenograft collagen and collagen membrane post-tooth extraction: A 6-month randomized controlled clinical trial. *The International Journal of Periodontics & Restorative Dentistry, 37*(5), e290–e296.

Jamjoom, A., & Cohen, R. E. (2015). Grafts for ridge preservation. *Journal of Functional Biomaterials, 6*(3), 833–848.

Johnson, K. (1969). A study of the dimensional changes occurring in the maxilla following tooth extraction. *Australian Dental Journal, 14*(4), 241–244.

Joshi, C. P., Dani, N. H., & Khedkar, S. U. (2016). Alveolar ridge preservation using autogenous tooth graft versus beta-tricalcium phosphate alloplastic: A randomized, controlled, prospective, clinical pilot study. *Journal of Indian Society of Periodontology, 20*(4), 429–434.

Jung, R. E., Fenner, N., Hämmerle, C. H. F., & Zitzmann, N. U. (2013a). Long-term outcome of implants placed with guided bone regeneration (GBR) using resorbable and non-resorbable membranes after 12-14 years. *Clinical Oral Implants Research, 24*(10), 1065–1073.

Jung, R. E., Philipp, A., Annen, B. M., Signorelli, L., Thoma, D. S., Hämmerle, C. H. F., Attin, T., & Schmidlin, P. (2013b). Radiographic evaluation of different techniques for ridge preservation after tooth extraction: A randomized controlled clinical trial. *Journal of Clinical Periodontology, 40*(1), 90–98.

Jung, R. E., Siegenthaler, D. W., & Hämmerle, C. H. F. (2004). Postextraction tissue management: A soft tissue punch technique. *The International Journal of Periodontics & Restorative Dentistry, 24*(6), 545–553.

Karaca, Ç., Er, N., Gülşahı, A., & Köseoğlu, O. T. (2015). Alveolar ridge preservation with a free gingival graft in the anterior maxilla: Volumetric evaluation in a randomized clinical trial. *International Journal of Oral and Maxillofacial Surgery, 44*(6), 774–780.

Kim, D. M., De Angelis, N., Camelo, M., Nevins, M. L., Schupbach, P., & Nevins, M. (2013). Ridge preservation with and without primary wound closure: A case series. *The International Journal of Periodontics & Restorative Dentistry, 33*(1), 71–78.

Kotsakis, G. A., Salama, M., Chrepa, V., Hinrichs, J. E., & Gaillard, P. (2014). A randomized, blinded, controlled clinical study of particulate anorganic bovine bone mineral and calcium phosphosilicate putty bone substitutes for socket preservation. *The International Journal of Oral & Maxillofacial Implants, 29*(1), 141–151.

Lascala, C. A., Panella, J., & Marques, M. M. (2004). Analysis of the accuracy of linear measurements obtained by cone-beam computed tomography (CBCT-NewTom). *Dento Maxillo Facial Radiology, 33*(5), 291–294.

Leblebicioglu, B., Salas, M., Ort, Y., Johnson, A., Yildiz, V. O., Kim, D.-G., Agarwal, S., & Tatakis, D. N. (2013). Determinants of alveolar ridge preservation differ by anatomic location. *Journal of Clinical Periodontology, 40*(4), 387–395.

Lekovic, V., Camargo, P. M., Klokkevold, P. R., Weinlaender, M., Kenney, E. B., Dimitrijevic, B., & Nedic, M. (1998). Preservation of alveolar bone in extraction sockets using bioabsorbable membranes. *Journal of Periodontology, 69*(9), 1044–1049.

Lekovic, V., Kenney, E. B., Weinlaender, M., Han, T., Klokkevold, P., Nedic, M., & Orsini, M. (1997). A bone regenerative approach to alveolar ridge maintenance following tooth extraction: Report of 10 cases. *Journal of Periodontology, 68*(6), 563–570.

MacBeth, N., Trullenque-Eriksson, A., Donos, N., & Mardas, N. (2017). Hard and soft tissue changes following alveolar ridge preservation: A systematic review. *Clinical Oral Implants Research, 28*(8), 982–1004.

Madan, R., Mohan, R., Bains, V. K., Gupta, V., Singh, G. P., & Madan, M. (2014). Analysis of socket preservation using polylactide and polyglycolide (PLA-PGA) sponge: A clinical, radiographic, and histologic study. *The International Journal of Periodontics & Restorative Dentistry, 34*(1), e36-42.

Mardas, N., Trullenque-Eriksson, A., MacBeth, N., Petrie, A., & Donos, N. (2015). Does ridge preservation following tooth extraction improve implant treatment outcomes: A systematic review: Group 4: Therapeutic concepts & methods. *Clinical Oral Implants Research, 26*(Suppl 11), 180–201.

Melcher, A. H. (1976). On the repair potential of periodontal tissues. *Journal of Periodontology, 47*(5), 256–260.

Morjaria, K. R., Wilson, R., & Palmer, R. M. (2014). Bone healing after tooth extraction with or without an intervention: A systematic review of randomized controlled trials. *Clinical Implant Dentistry and Related Research, 16*(1), 1–20.

Nasr, H. F., Aichelmann-Reidy, M. E., & Yukna, R. A. (1999). Bone and bone substitutes. *Periodontology 2000, 19*, 74–86.

Pagni, G., Pellegrini, G., Giannobile, W. V., & Rasperini, G. (2012). Postextraction alveolar ridge preservation: Biological basis and treatments. *International Journal of Dentistry, 2012*.

Pang, C., Ding, Y., Zhou, H., Qin, R., Hou, R., Zhang, G., & Hu, K. (2014). Alveolar ridge preservation with deproteinized bovine bone graft and collagen membrane and delayed implants. *The Journal of Craniofacial Surgery, 25*(5), 1698–1702.

Peregrine, A. A., da Costa, C. E. S., Correa, M. E. P., & Marques, J. F. C. (2010). Clinical and histomorphometric evaluation of extraction sockets treated with an autologous bone marrow graft. *Clinical Oral Implants Research, 21*(5), 535–542.

Pietrokovski, J., & Massler, M. (1967a). Alveolar ridge resorption following tooth extraction. *The Journal of Prosthetic Dentistry, 17*(1), 21–27.

Pietrokovski, J., & Massler, M. (1967b). Ridge remodeling after tooth extraction in rats. *Journal of Dental Research, 46*(2), 222–231.

Pinho, M. N., Roriz, V. L. M., Novaes, A. B., Taba, M., Grisi, M. F. M., de Souza, S. L. S., & Palioto, D. B. (2006). Titanium membranes in the prevention of alveolar collapse after tooth extraction. *Implant Dentistry, 15*(1), 53–61.

Rasperini, G., Canullo, L., Dellavia, C., Pellegrini, G., & Simion, M. (2010). Socket grafting in the posterior maxilla reduces the need for sinus augmentation. *The International Journal of Periodontics & Restorative Dentistry, 30*(3), 265–273.

Schropp, L., Isidor, F., Kostopoulos, L., & Wenzel, A. (2005). Interproximal papilla levels following early versus delayed placement of single-tooth implants: A controlled clinical trial. *The International Journal of Oral & Maxillofacial Implants, 20*(5), 753–761.

Schropp, L., Kostopoulos, L., & Wenzel, A. (2003a). Bone healing following immediate versus delayed placement of titanium implants into extraction sockets: A prospective clinical study. *The International Journal of Oral & Maxillofacial Implants, 18*(2), 189–199.

Schropp, L., Wenzel, A., Kostopoulos, L., & Karring, T. (2003b). Bone healing and soft tissue contour changes following single-tooth extraction: A clinical and radiographic 12-month prospective study. *The International Journal of Periodontics & Restorative Dentistry, 23*(4), 313–323.

Serino, G., Sato, H., Holmes, P., & Turri, A. (2017). Intra-surgical vs radiographic bone level assessments in measuring peri-implant bone loss. *Clinical Oral Implants Research, 28*(11), 1396–1400.

Tan, W. L., Wong, T. L. T., Wong, M. C. M., & Lang, N. P. (2012). A systematic review of post-extraction alveolar hard and soft tissue dimensional changes in humans. *Clinical Oral Implants Research, 23*(Suppl 5), 1–21.

Tarnow, D. P., Eskow, R. N., & Zamzok, J. (1996). Aesthetics and implant dentistry. *Periodontology 2000, 11*, 85–94.

Thalmair, T., Fickl, S., Schneider, D., Hinze, M., & Wachtel, H. (2013). Dimensional alterations of extraction sites after different alveolar ridge preservation techniques - A volumetric study. *Journal of Clinical Periodontology, 40*(7), 721–727.

Thoma, D. S., Benić, G. I., Zwahlen, M., Hämmerle, C. H. F., & Jung, R. E. (2009). A systematic review assessing soft tissue augmentation techniques. *Clinical Oral Implants Research, 20*(Suppl 4), 146–165.

Troiano, G., Zhurakivska, K., Lo Muzio, L., Laino, L., Cicciù, M., & Lo Russo, L. (2018). Combination of bone graft and resorbable membrane for alveolar ridge preservation: A systematic review, meta-analysis, and sequential trial analysis. *Journal of Periodontology, 89*(1), 46–57.

Van der Weijden, F., Dell'Acqua, F., & Slot, D. E. (2009). Alveolar bone dimensional changes of post-extraction sockets in humans: A systematic review. *Journal of Clinical Periodontology, 36*(12), 1048–1058.

Vignoletti, F., Matesanz, P., Rodrigo, D., Figuero, E., Martin, C., & Sanz, M. (2012). Surgical protocols for ridge preservation after tooth extraction: A systematic review. *Clinical Oral Implants Research, 23*(Suppl 5), 22–38.

Vittorini Orgeas, G., Clementini, M., De Risi, V., & de Sanctis, M. (2013). Surgical techniques for alveolar socket preservation: A systematic review. *The International Journal of Oral & Maxillofacial Implants, 28*(4), 1049–1061.

Walker, C. J., Prihoda, T. J., Mealey, B. L., Lasho, D. J., Noujeim, M., & Huynh-Ba, G. (2017). Evaluation of healing at molar extraction sites with and without ridge preservation: A randomized controlled clinical trial. *Journal of Periodontology, 88*(3), 241–249.

Wang, R. E., & Lang, N. P. (2012). Ridge preservation after tooth extraction. *Clinical Oral Implants Research, 23*(Suppl 6), 147–156.

Willenbacher, M., Al-Nawas, B., Berres, M., Kämmerer, P. W., & Schiegnitz, E. (2016). The effects of alveolar ridge preservation: A meta-analysis. *Clinical Implant Dentistry and Related Research, 18*(6), 1248–1268.

Wood, D. L., Hoag, P. M., Donnenfeld, O. W., & Rosenfeld, L. D. (1972). Alveolar crest reduction following full and partial thickness flaps. *Journal of Periodontology, 43*(3), 141–144.