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Primary flap closure in alveolar ridge preservation for periodontally damaged extraction socket: A randomized clinical trial

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Abstract

Introduction: The effect of primary wound closure (PC) on alveolar ridge preservation (ARP) in periodontally damaged sockets has yet to be fully discovered.

Methods: Periodontally damaged sockets were allocated to one of the following groups: (1) ARP with PC (group PC), and (2) ARP without PC (group secondary wound closure [SC]). Following tooth extraction and flap elevation, granule-type xenogeneic bone substitute material and a collagen barrier were applied. Ridge change was evaluated using cone-beam computed tomographic (CBCT) scans immediately after ARP and at 4 months. Core biopsy specimens were examined histomorphometrically.

Results: A total of 28 patients were included in the analysis (13 in group PC, 15 in group SC). Histomorphometrically, the percentage of newly formed bone was 26.2 ± 17.7% and 24.6 ± 18.4% in groups PC and SC, respectively (independent *t*-test, degree of freedom [df] = 25, $p > 0.05$). Horizontal ridge changes on CBCT were −4.9 ± 3.1 mm and − 4.2 ± 2.5 mm in groups PC and SC at the 1 mm level below the ridge crest, respectively (independent *t*-test, df = 26, $p > 0.05$). Approximately half of the sites required additional bone augmentation at implant placement.

Conclusions: ARP with/without PC yielded similar new bone formation and radiographic ridge change.

This clinical trial was not registered prior to participant recruitment and randomization (https://cris.nih.go.kr/cris/search/detailSearch.do/19718).

KEYWORDS
alveolar ridge preservation, cone-beam computed tomography, histomorphometry, primary flap closure

Summary Box

What is known

- For intact or minimally damaged sockets, alveolar ridge preservation (ARP) is generally performed without primary wound closure.

Gil-Jong Seo and Hyun-Chang Lim contributed equally to this study.

- However, ARP for periodontally damaged extraction sockets might be similar to guided bone regeneration.
- The effect of primary wound closure on ARP for periodontally damaged extraction sockets has yet to be fully investigated.

What this study adds

- For periodontally damaged sockets, no significant difference was noted between ARPs with/without primary wound closure in terms of new bone formation, hard tissue change, patient discomfort, and the need for additional augmentation.
- PC may not be mandatory in ARP even for periodontally damaged sockets.

1 | INTRODUCTION

Tooth extraction leads to various extents of alveolar ridge resorption.[1–3] Such resorption worsens the condition of local hard tissue, potentially resulting in negative impacts on implant treatment. Various methods have therefore been introduced for maintaining ridge dimensions, one of which is alveolar ridge preservation (ARP).[4–6] Current evidence demonstrates that ARP is effective in minimizing ridge shrinkage (1.99 mm horizontally and 1.72 mm vertically less than extraction alone)[7] and facilitating implant placement (between 88.9% and 100%).[8]

ARP generally involves using a bone substitute material and a barrier membrane. Such may make many clinicians regard ARP as similar to guided bone regeneration (GBR). However, most ARP procedures tend to exclude primary wound closure (PC), which may result in significant differences between ARP and GBR. Nonetheless, ARPs with/without PC exhibited comparably different effects on ridge dimension maintenance and new bone formation.[9,10] Moreover, morbidity and coronal shift of the mucogingival junction are smaller in patients who received ARP without PC (secondary wound closure [SC]) than in ARP with PC.[11]

However, the extent of socket wall destruction may be a confounder for applying the above findings to real clinical settings. Previous studies mostly targeted intact or minimally damaged sockets,[10,11] but many extraction sockets are periodontally damaged in clinical settings. There are literature reports on several differences between periodontally damaged and intact sockets. First, the extent of ridge resorption after extraction was greater in the damaged than in the intact socket.[12,13] Second, post-extraction bone remodeling was delayed in damaged sockets in terms of bone-forming rate and cortication.[14,15] Third, when applying ARP to damaged sockets, ridge contours are inevitably recreated along the imaginary pre-existing contour[16,17] or are over-contoured relative to the adjacent ridge.[18] The above observations suggest that ARP requires the healing of periodontally damaged sockets to take place in a fully closed environment, such as in GBR.[4,19] There is also evidence of inferior bone formation at GBR sites with wound dehiscence compared with uneventfully healed sites.[20–22] Thus, in the context of GBR, PC might be needed in ARP for periodontally damaged sockets.

A null hypothesis in the present randomized clinical trial was that in periodontally damaged sockets, ARP with PC does not lead to superior histologic new bone formation relative to ARP with SC. In addition to histomorphometric outcomes, radiographic, patient-reported, and implant-related outcomes were also investigated.

2 | MATERIALS AND METHODS

2.1 | Study design

This study was designed as a prospective randomized clinical trial in accordance with the 1975 Declaration of Helsinki (revised in Fortaleza in 2013) and the Good Clinical Practice guidelines. The research protocol of this study was approved by the Institutional Review Board for Clinical Research at the Kyung Hee University Dental Hospital (approval no.: KT-DT19001) and registered in the Clinical Research Information Service (https://cris.nih.go.kr/cris/search/detailSearch.do/19718). The CONSORT guidelines were observed during the writing of the manuscript.

2.2 | Study population

Patients who required non-molar tooth extraction and dental implant placement from March 2019 to December 2020 were recruited in the Department of Periodontology of Kyung Hee University Dental Hospital. Informed consent was obtained from each participant by an independent research assistant. The inclusion criteria were as follows: (1) between 20 and 75 years old, (2) adequate oral hygiene for oral surgery, and (3) non-molar tooth classification of type III or IV by Caplanis et al.[23] The exclusion criteria were as follows: (1) heavy smoking habit (>10 cigarettes per day), (2) systematic conditions hampering healing after surgery (e.g., uncontrolled diabetes mellitus, radiation therapy at the head and neck region, autoimmune disease, chemotherapy, or bisphosphonate medication), (3) pregnancy or lactation, (4) alcoholism, (5) drug abuse, or (6) untreated or uncontrolled periodontal disease.

2.3 | Study groups

- Group PC: ARP using a granule-type bovine bone substitute material (InterOss, SigmaGraft, Fullerton, USA) and a native bilayer collagen membrane (Bio-Gide, Geistlich, Wulhusen, Switzerland), followed by PC.

- Group SC: ARP using the biomaterials mentioned above, followed by SC.

2.4 | Group assignments

The patients were assigned to sequential numbers according to their enrolment order. Random group allocation was performed with block sizes of 4 and 6 using R statistical software, and then the allocations were sealed in opaque envelopes by an independent investigator.

2.5 | Surgical procedures

The surgeries were performed by two faculty members (Seung-Yun Shin and Hyun-Chang Lim) and four senior residents. The faculty members supervised all surgeries of the residents.

2.5.1 | Alveolar ridge preservation

Tooth extraction was performed after local anesthesia (articaine containing 1:100 000 epinephrine, Huons, Seongnam, Korea). A full-thickness flap was reflected, and meticulous degranulation was performed. The bone substitute material was then grafted to produce a slight horizontal overcontour relative to the adjacent bony envelope, but with no vertical overfilling. The grafted bone substitute material was completely covered by a collagen membrane. The flap was then coronally advanced using a periosteal releasing incision (with/without vertical incision) in group PC, followed by PC using mattress and interrupted sutures. Primary closure was not attempted in group SC (Figure 1). Sutures were removed 7–10 days later, at which time the patients were asked to report their discomfort levels after ARP on a 10 cm-scale bar ranging from 0 (none) to 10 (extreme discomfort).

2.5.2 | Implant placement

After 4 months, after full-thickness flap elevation, a bone core biopsy was performed using a trephine bur. A bone-level implant was then placed according to the guideline of the manufacturer. Additional bone augmentation was performed when the bone plate was thin (<1 mm) and a bony dehiscence presented on the implant surface. A healing abutment or cover screw was connected to the implant.

2.5.3 | Post-surgical care after ARP and implant placement

The patients were prescribed antibiotics and analgesics for 5–7 days according to the preferences of their clinicians. The patients were instructed to rinse a 0.12% chlorhexidine solution twice daily until suture removal.

2.6 | Outcome measures

2.6.1 | Primary outcome

- % NB in bone core biopsy.

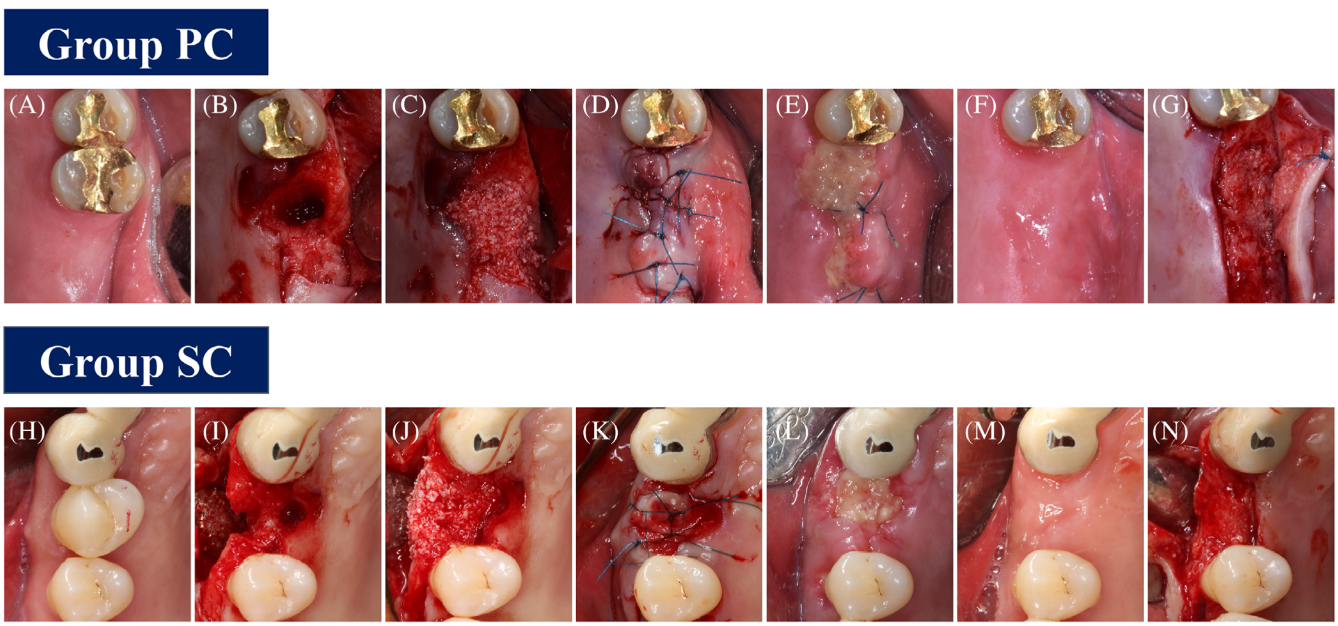

FIGURE 1 Representative photographs of groups with primary flap closure (PC) (A–G) and secondary wound closure (SC) (H–N). (A, H) Clinical situation before tooth extraction; (B, I) immediately after tooth extraction; (C, J) after bone substitute material applied; (D, K) after suturing; (E, L) clinical situation at the time of suture removal; (F, M) clinical situation after 4 months; (G, N) bone healing at the time of implant placement (after 4 months). Group PC, alveolar ridge preservation (ARP) with primary wound closure (PC); group SC, ARP with SC.

2.6.2 | Secondary outcomes

- Percentages of residual bone substitute material (%RM) in bone core biopsy.
- Horizontal/vertical ridge changes between immediately after ARP (T1) and 4 months later (T2), assessed using cone-beam computed tomography (CBCT).
- Frequency of additional bone augmentation at implant placement.
- Patient discomfort level assessed using a visual analog scale (VAS).

2.7 | Analyses

All analyses were conducted by one investigator (Gil-Jong Seo) without informing them of the group assignments and while supervised by a senior investigator (Hyun-Chang Lim). Prior to analyses, five relevant samples for each analytic category were provided to both investigators, then measurements were made, and the values of each category were compared. When the interclass correlation coefficient did not reach 0.9 (with a 95% confidence interval), the above procedure was repeated.

2.7.1 | Histologic and histomorphometric analyses

The harvested bone cores were fixed in a 10% neutral buffered formalin solution, decalcified, and embedded in paraffin. The specimens were then sectioned at a 4-μm thickness along the longitudinal axis of the specimen, followed by Masson's trichrome staining. All histologic slides were digitally scanned (PANNORAMIC 250 Flash III, 3DHISTECH, Budapest, Hungary). Subsequently, the areas of newly formed bone (NB) and residual bone substitute material (RM) were measured (CaseViewer, 3DHISTECH), and %NB and %RM were calculated with respect to the total area of the specimen (Figure S1 in Appendix S1). %NB and %RM in the apical and coronal halves of each specimen were also calculated. Histomorphometric results were also sorted by sex, jaw (maxilla vs. mandible), and defect classification (Class III vs. Class IV).

2.7.2 | Radiographic analysis

CBCT was performed at T1 and T2, and the obtained data were first superimposed using an autoaligning tool and then manually adjusted using OnDemand3D software (Cybermed, Daejeon, Korea). On the superimposed images, a vertical reference line was drawn along the longitudinal axis of the extraction socket in the coronal plane. Three horizontal reference lines were subsequently drawn at 1 mm (BW_1), 3 mm (BW_3), and 5 mm (BW_5) below the most-coronal part of the augmented ridge, perpendicular to the vertical reference[24] (Figure S1). The ridge widths at BW_1, BW_3, and BW_5 were measured at T1 and T2, and the difference between T1 and T2 was then calculated (ΔBW_1, ΔBW_3, and ΔBW_5, respectively). The difference in vertical bone heights at the midcrestal area was also measured.

2.8 | Statistics

Data are presented as mean ± SD or median [interquartile range] values. The Shapiro–Wilk test was performed to determine whether data conformed to normal distribution. The independent *t*-test and Mann–Whitney *U* test were used for intergroup comparisons. Intragroup comparisons for %NB/% RM between apical and coronal portions were performed using the paired *t*-test and Wilcoxon signed-rank test. The chi-square test was used to determine the frequency of need for further bone augmentation at the time of implant placement. Statistically significant difference was set at $p < 0.05$.

3 | RESULTS

This study initially enrolled 30 patients. Two patients dropped out due to acute hepatitis and withdrawal of consent, leading to 28 patients completing the study: 13 and 15 in groups PC and SC, respectively (Figure S2). The demographics and relevant clinical information of patients are listed in Table 1.

At the time of suture removal, wound dehiscence was noted in 8 of the 13 patients in group PC. However, there were no other specific adverse events such as persistent swelling, bleeding or pus discharge during the healing period.

3.1 | Histologic and histomorphometric outcomes

3.1.1 | Histologic observations

NB was greater in the apical area than in the coronal area. In the most-apical area, NB appeared to be more mature than that in the upper area. NB was mostly in contact with the bone substitute particles, which were smaller in the coronal area than in the apical area. Some particles were embedded in the soft tissue (Figure 2A).

TABLE 1 Demographics and relevant clinical information

	Group PC ($n = 13$)	Group SC ($n = 15$)
Age (years)	54.4 ± 11.3	54.9 ± 7.4
Sex (male/female)	10/3	11/4
Jaw (mandible/maxilla)	4/9	3/12
Site (incisor/canine/premolar)	1/1/11	1/0/14
Extraction socket classification (according to Caplanis et al.[23]) (type III/type IV)	6/7	8/7
Implant diameter (in mm) (3.1/3.6/4.0/4.1/4.5)	1/1/3/0/8	0/1/3/1/10
Need for additional bone augmentation	6	8

Note: Data are mean ± SD or *n* values. Group PC, alveolar ridge preservation (ARP) with primary wound closure (PC); Group SC, ARP with secondary wound closure (SC).

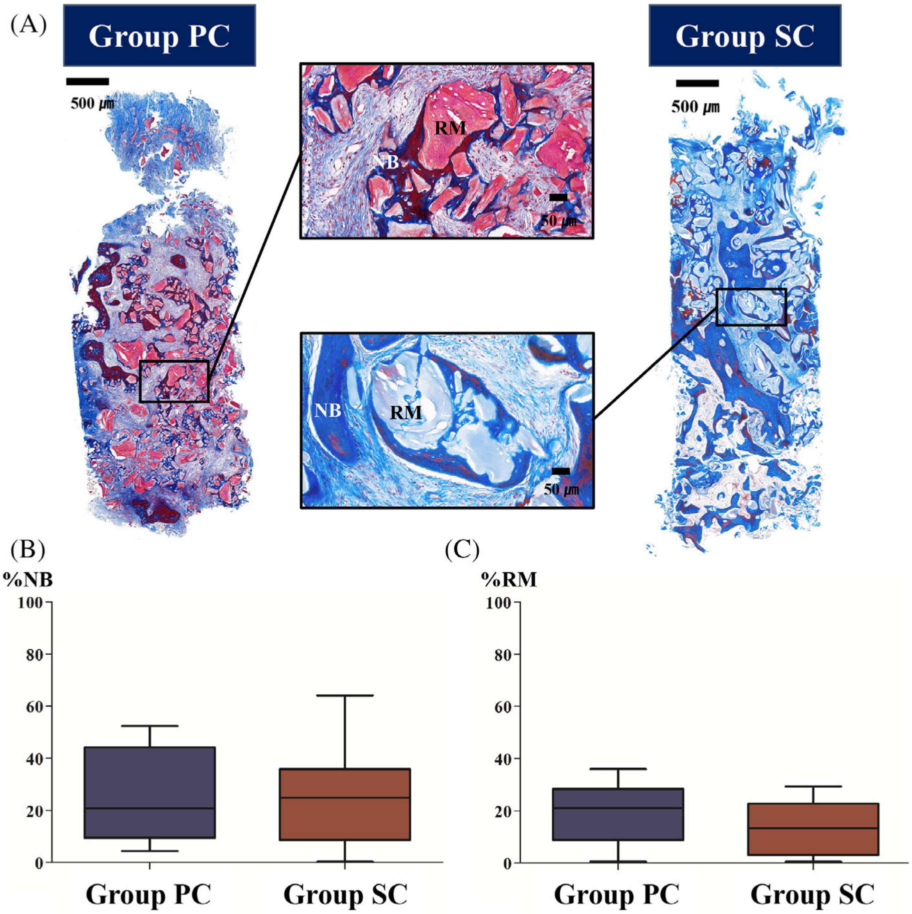

FIGURE 2 Representative histologic images and box-and-whisker plots showing the histomorphometric results of groups PC (purple) and SC (brown). (A) Representative histologic images of the groups; (B) %NB; (C) %RM. The whiskers cover the entire data range. The line and + symbol within each box indicate mean and median values, respectively. Group PC: alveolar ridge preservation (ARP) with primary wound closure (PC); group SC: ARP with secondary wound closure (SC).

3.1.2 | Histomorphometric analysis

One specimen in group SC was excluded from the analysis due to fragmentation occurring when harvesting the specimen. The values of histomorphometric parameters and statistical information are present in Table 2.

The overall %NB was 26.2 ± 17.7% in group PC and 24.6 ± 18.4% in group SC, while %RM was 18.9 ± 11.0% and 14.1 ± 9.6%, respectively, with no significant intergroup difference in either ($p > 0.05$) (Figure 2B, C, Table 2). For spatial difference (apical vs. coronal segments), the apical %NB was significantly higher than the coronal %NB in both groups ($p < 0.05$). There was no statistically significant intergroup difference between the same segments of each group ($p > 0.05$). No significant intergroup or intragroup difference was noted according to location, sex or defect classification ($p > 0.05$) (Table 2).

Due to the wound dehiscence in group PC, only five patients met the per-protocol set. When comparing those five patients with the remnants within group PC, %NB in the patients with successful/unsuccessful PC was 33.9 ± 19.3% and 21.4 ± 16.1% (Table S1).

3.2 | Radiographic outcomes

The values of radiographic parameters and statistical information are present in Table 3.

Horizontally, at all measured levels (BW_1, BW_3, and BW_5), there were subtractive ridge changes in both groups (Figure 3A). At T2, the uppermost part of the ridge was located below BW_1 (at T1) in seven patients in group PC and five in group SC. The horizontal changes in the group PC were −4.9 ± 3.1 mm at BW_1, −3.0 ± 2.4 mm at BW_3, and −1.7 ± 1.4 mm at BW_5. The corresponding values in group SC were −4.2 ± 2.5 mm, −3.0 ± 2.7 mm, and − 1.6 ± 1.2 mm, respectively. There were no significant intergroup differences at any level ($p > 0.05$). Vertically, the mid-crestal level shifted apically over time (−1.4 ± 1.2 mm in group PC and −0.9 ± 1.5 mm in group SC) with no significant difference between the groups ($p > 0.05$) (Figure 3B,C, Table 3).

When PC was successfully achieved in group PC, the horizontal change at BW_1 was greater than in the patients with unsuccessful PC (−5.9 ± 3.2 vs. −4.2 ± 3.0 mm). The changes in other levels were similar between the patients with successful and unsuccessful PC (Table S1).

3.3 | Frequency of additional augmentation

Additional bone augmentation was performed on 6 of 13 patients in group PC (46.2%) and on 8 of 15 patients in group SC (53.3%) for the following reasons: bony dehiscence ($n = 3$) and thin buccal bone plate smaller than 1 mm ($n = 3$) in group PC; and bony dehiscence ($n = 6$),

TABLE 2 Histomorphometric analyses in groups PC and SC

			Group PC	Group SC	*p*-Value
%NB	Total (*n* = 13 vs. 14, df = 25)		26.2 ± 17.7 20.8 [9.4, 44.2]	24.6 ± 18.4 24.8 [8.8, 35.8]	0.826[a]
	Region	Apical (*n* = 13 vs. 14, df = 25)	15.4 ± 9.4 12.7 [6.5, 23.8]	15.5 ± 10.2 17.8 [7.9, 22.7]	0.981[a]
		Coronal (*n* = 13 vs. 14, df = 25)	10.8 ± 8.6 8.1 [3.2, 19.6]	9.1 ± 9.6 4.8 [1.4, 14.8]	0.452[b]
		p	<0.001[c,*] (df = 11)	0.006[c,*] (df = 12)	
	Jaw	Maxilla (*n* = 9 vs. 11, df = 18)	26.4 ± 18.1 20.8 [9.3, 44.2]	22.1 ± 15.9 22.0 [5.0, 34.5]	0.578[a]
		Mandible (*n* = 4 vs. 3, df = 5)	25.7 ± 19.6 24.2 [7.7, 45.0]	33.9 ± 27.6 27.7 [10.0, 64.1]	0.660[a]
		p	0.948[a] (df = 11)	0.343[a] (df = 12)	
	Sex	Male (*n* = 10 vs. 10, df = 18)	23.8 ± 18.9 15.1 [5.8, 44.0]	25.3 ± 20.0 24.8 [7.7, 37.3]	1.000[b]
		Female (*n* = 3 vs. 4, df = 5)	34.1 ± 12.6 35.5 [20.8, 45.9]	22.8 ± 16.2 23.2 [7.2, 38.0]	0.289[b]
		p	0.403[a] (df = 11)	0.826[a] (df = 12)	
	Socket classification	Class III (*n* = 6 vs. 8, df = 12)	30.3 ± 20.8 35.7 [5.2, 49.2]	28.5 ± 20.2 24.8 [10.9, 44.4]	0.876[a]
		Class IV (*n* = 7 vs. 6, df = 11)	22.6 ± 15.5 17.1 [12.9, 42.6]	19.4 ± 15.8 24.0 [0.8, 33.1]	0.716[a]
		p	0.462[a] (df = 11)	0.377[a] (df = 12)	
%RM	Total (*n* = 13 vs. 14, df = 25)		18.9 ± 11.0 21.1 [8.8, 28.4]	14.1 ± 9.6 13.3 [3.1, 22.7]	0.240[a]
	Region	Apical (*n* = 13 vs. 14, df = 25)	7.8 ± 5.6 8.8 [2.4, 4.0]	5.8 ± 5.9 3.5 [0.4, 11.8]	0.225[b]
		Coronal (*n* = 13 vs. 14, df = 25)	11.1 ± 6.4 11.8 [5.2, 16.7]	8.3 ± 5.6 9.2 [2.4, 12.2]	0.225[b]
		p	0.032[c,*] (df = 11)	0.167[d] (df = 12)	
	Jaw	Maxilla (*n* = 9 vs. 11, df = 18)	18.0 ± 11.5 21.1 [6.1, 28.4]	13.8 ± 9.1 13.4 [3.3, 22.2]	0.380[a]
		Mandible (*n* = 4 vs. 3, df = 5)	20.9 ± 11.2 18.4 [11.7, 32.6]	15.1 ± 13.5 13.2 [2.6, 29.4]	0.557[a]
		p	0.676[a] (df = 11)	0.854[a] (df = 12)	
	Sex	Male (*n* = 10 vs. 10, df = 18)	21.3 ± 10.5 23.2 [12.3, 31.3]	13.3 ± 9.2 12.7 [3.1, 19.6]	0.059[b]
		Female (*n* = 3 vs. 4, df = 5)	10.9 ± 10.2 10.9 [0.6, 21.1]	16.0 ± 11.7 18.7 [3.7, 25.6]	0.480[b]
		p	0.158[a] (df = 11)	0.656[a] (df = 12)	
	Socket classification	Class III (*n* = 6 vs. 8, df = 12)	18.4 ± 10.5 14.9 [9.9, 31.3]	13.6 ± 11.7 12.6 [1.6, 25.6]	0.451[a]
		Class IV (*n* = 7 vs. 6, df = 11)	19.3 ± 12.2 22.5 [5.5, 25.5]	14.7 ± 6.7 15.9 [10.0, 19.6]	0.432[a]
		p	0.886[a] (df = 11)	0.841[a] (df = 12)	

Note: Data are mean ± SD or median [interquartile range] values. Group PC, alveolar ridge preservation (ARP) with primary wound closure (PC); Group SC, ARP with secondary wound closure (SC); %NB, percentage of newly formed bone (NB) in a bone core biopsy; %RM, percentage of residual bone substitute material (RM) in a bone core biopsy; *n*, numbers of patients in group PC vs. group SC.

[a]Independent *t*-test.

[b]Mann–Whitney *U* test.

[c]Paired *t*-test.

[d]Wilcoxon signed-rank test df: degree of freedom.

*Significant intragroup difference: $p < 0.05$.

TABLE 3 Radiographic ridge changes in groups PC and SC

	Group PC ($n = 13$)	Group SC ($n = 15$)	p-Value
Ridge width at T1			
BW_1	6.9 ± 2.1 6.3 [5.2, 8.0]	7.3 ± 2.1 6.7 [5.3, 9.4]	0.612[b]
BW_3	9.5 ± 1.4 9.7 [8.5, 10.7]	9.8 ± 1.7 9.7 [8.5, 11.2]	0.610[a]
BW_5	10.4 ± 1.6 11.0 [9.0, 11.6]	10.7 ± 1.7 10.5 [9.1, 12.0]	0.705[a]
Ridge width at T2			
BW_1	2.0 ± 2.6 0.0 [0.0, 4.8]	3.1 ± 2.4 0.0 [0.0, 6.1]	0.259[b]
BW_3	6.5 ± 2.7 7.2 [3.2, 8.3]	6.8 ± 3.1 8.1 [4.6, 9.1]	0.756[a]
BW_5	8.8 ± 1.9 8.9 [7.6, 10.3]	9.1 ± 2.1 9.5 [7.6, 11.0]	0.678[a]
Horizontal changes			
ΔBW_1	−4.9 ± 3.1 −4.9 [−6.7, −2.4]	−4.2 ± 2.5 −3.3 [−5.6, −2.4]	0.529[a]
ΔBW_3	−3.0 ± 2.4 −2.5 [−4.4, −1.4]	−3.0 ± 2.7 −3.6 [−5.5, −0.6]	0.782[b]
ΔBW_5	−1.7 ± 1.4 −1.6 [−2.3, −0.7]	−1.6 ± 1.2 −1.6 [−2.1, −0.6]	1.000[b]
Vertical changes			
	−1.4 ± 1.2 −1.4 [−2.3, −0.7]	−0.9 ± 1.5 −2.0 [−2.0, −0.5]	0.349[a]

Note: Data are mean ± SD or median [interquartile range] values in millimeters. Group PC, alveolar ridge preservation (ARP) with primary wound closure (PC); Group SC, ARP with secondary wound closure (SC); BW_1, BW_3, and BW_5, horizontal hard-tissue widths at 1, 3, and 5 mm below the ridge crest; ΔBW_1, ΔBW_3, and ΔBW_5: changes in horizontal hard-tissue width at 1, 3, and 5 mm below the ridge crest. T1, immediately after ARP; T2, 4 months after ARP. In all comparison, degree of freedom is 26.
[a]Independent t-test.
[b]Mann–Whitney U test.

the need for correcting concavity with respect to adjacent bone envelope ($n = 1$) and poor bone quality ($n = 1$) in group SC. The number of patients needing further bone augmentation did not differ significantly between the two groups ($p > 0.05$).

3.4 | Patient-reported outcome

The discomfort level of patients was greater following ARP in group PC compared with group SC (3.9 ± 2.8 vs. 2.4 ± 2.4), but the difference was not significant ($p > 0.05$) (Figure S3).

4 | DISCUSSION

This study investigated the effects of primary wound closure (PC) on the outcomes of ARP in periodontally damaged sockets. The null hypothesis of this study was not rejected, since no significant differences were found in NB formation between groups PC and SC. Furthermore, the two groups demonstrated no distinct difference in hard-tissue changes, discomfort levels of patients, and frequency of additional bone augmentation.

4.1 | Histomorphometric outcomes

In this study, %NB was similar in the groups (26.2 ± 17.7% vs. 24.6 ± 18.4% in groups PC and SC, respectively), which was in accordance with previous studies on the same topic; 22.5 ± 3.9% vs. 22.5 ± 4.3%,[9] and 40.3 ± 7.8% vs. 47.3 ± 11.3%.[10] This suggests that PC is not necessarily required in ARP, despite different inclusion criteria for the sockets between the studies (above ones and the present study) and impaired new bone formation in the study dealing with the membrane exposure after GBR.[25] The exclusion of PC in ARP leads to the simplicity of clinical treatment, reduced chair time, and high availability for both patients and clinicians.

Nonetheless, in the per-protocol set fulfilling successful PC, %NB was greater than the patients with unsuccessful PC and SC. Such might indicate that the concept of GBR can be partially applied to ARP for the damaged sockets. Thus, the necessity of a PC should be determined to suit individual situations.

It should be emphasized that the NB values in this study were inferior to those in other systematic reviews, which found more than 30% of NB. When pooling outcomes specifically from xenogeneic bone substitute material and 4 months of healing, the NB values ranged between 30% and 39%.[26–28] Such a difference appears to be attributable to the characteristics of extraction sockets included in previous reviews (e.g., intact or minimally destructed or periodontally damaged or all of these combined), because the socket morphology markedly influences bone formation. Histologically, new bone formation starts at the socket walls. Moreover, the stability of the blood clot and graft material improved as the number of socket walls increased.

The %NB values found in this study somewhat corroborate those found in other studies of damaged sockets. In the studies by Sun et al. and Koo et al., these values were 19.52 ± 9.15%[29] and 16.71 ± 11.12%, respectively.[30] Specifically, the latter study demonstrated NB distributions between 0% and 43%. This highly variable bone formation was also observed in the present study (between 4.4% and 52.4% in group PC and between 0.4% and 64.1% in group SC). In contrast, other studies of damaged sockets found higher %NB values than in the above studies, such as 29.0 ± 9.3%,[31] 29.81 ± 9.03%,[32] 30.87 ± 17.27%,[33] and 49%.[34] Some reasons for these discrepancies can be speculated: (1) the healing period post-ARP was 4 months in the former studies[29,30] and the present study, but was 6 months and 12 months in the latter ones[31–34]; (2) the diversity of socket morphology played a certain role, and standardizing the morphology of damaged sockets has been difficult despite a recent attempt to categorize socket destruction[30,35]; and (3) the chronicity of alveolus inflammation could not be quantified. It can be assumed that more chronic inflammation results in less healing.

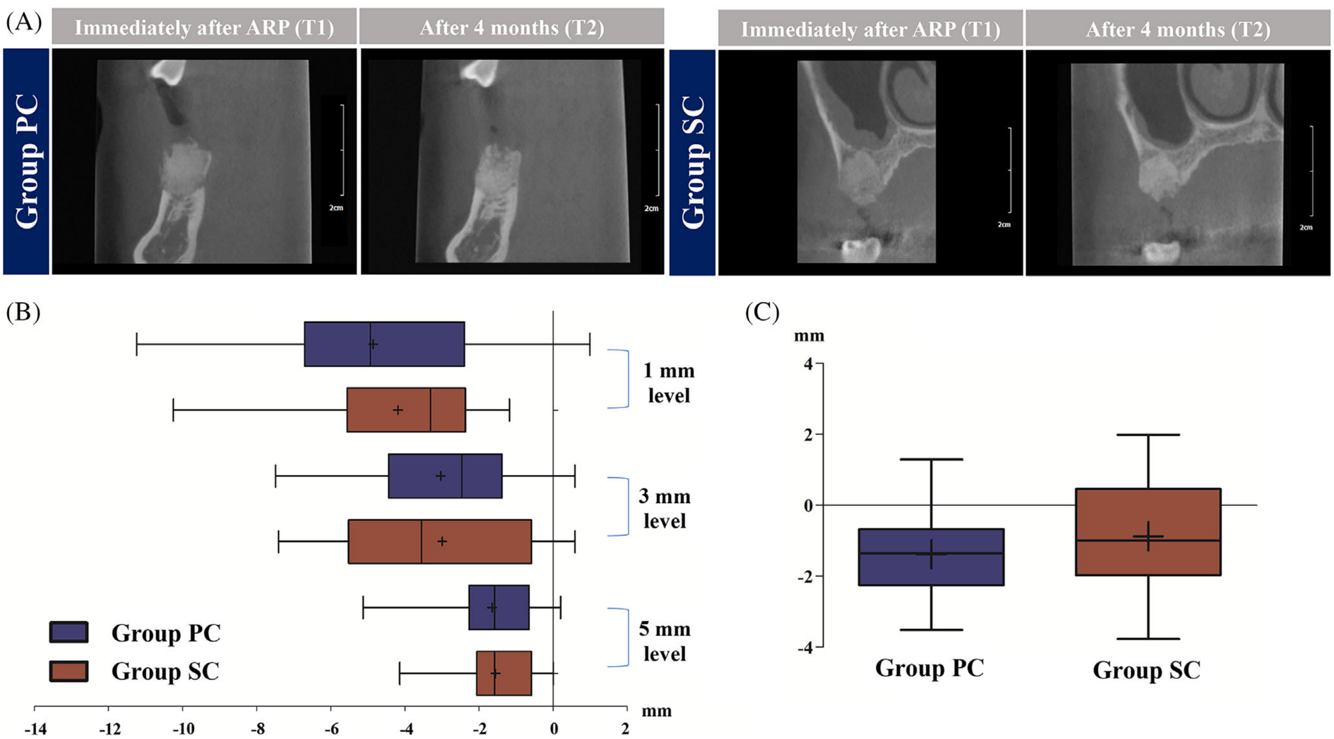

FIGURE 3 Representative radiographic images and box-and-whisker plots showing radiographic hard-tissue changes in groups PC (purple) and SC (brown). (A) Representative image of the groups; (B) Horizontal changes measured at 1 mm, 3 mm, and 5 mm below the ridge crest; (C) vertical change at the center of the ridge. The whiskers cover the entire data range. The line and + symbol within each box indicate mean and median values, respectively. Group PC: alveolar ridge preservation (ARP) with primary wound closure (PC); group SC: ARP with secondary wound closure (SC).

4.2 | Radiographic hard-tissue changes

In this study, subtractive hard-tissue changes were demonstrated at all measuring levels, which was consistent with the previous finding that complete ridge maintenance is not attainable. Furthermore, when comparing groups PC and SC, there was no significant intergroup difference in hard-tissue changes, indicating that the attempt to obtain PC in ARP for damaged sockets does not guarantee the optimal ridge width for implant placement. Several systematic reviews have dealt with this issue through subgroup analyses.[7,36–38] Among them, two only included intact or minimally damaged sockets,[36,38] and the other two did not exclude damaged sockets.[7,37] The former exhibited a tendency favoring ARP without PC for horizontal ridge changes, with mean differences of −0.91 and − 0.64 mm at sites treated ARP with and without PC compared with naturally healed sites, respectively. The latter also found that PC did not additionally benefit ARP. However, it should be noted that there is a lack of study about the effect of PC solely for damaged sockets. In the per-protocol set in group PC of the present study, when PC was successful, the horizontal change at BW_1 was greater than the situations with unsuccessful PC and SC.

The ridge width reductions in this study (−4.9 ± 3.1 mm in group PC and −4.2 ± 2.5 mm in group SC, measured at the most-crestal level) should be compared with other studies of damaged sockets (e.g., −1.02 ± 0.88,[24] −2.5 ± 1.9 ,[29] −2.60 ± 1.24,[12] −2.81 ± 4.47 and − 2.5 ± 4.73,[39] −5.56 ± 4.59,[33] and − 5.27 mm[40]). The difference between studies might be somewhat attributable to the surgical protocol. In the present study, it was tried to create a ridge shape as optimal as possible to prevent additional bone augmentation at the time of implant placement, which led to overaugmentation with respect to the imaginary outline connecting the adjoining ridge. This might cause unwanted pressure to the overaugmented area during the healing period and a subsequent significant amount of shrinkage.[18,40]

The positive effect of ARP in maintaining the alveolus dimensions is well-documented. Methodologically, this effect was manifested by comparing sockets that received ARP and naturally healed sockets in systematic reviews.[5,7,41,42] Only one systematic review specifically demonstrated the effect of ARP on damaged sockets, with mean differences of 2.37 mm in width and of 1.1 mm in height compared with sockets that did not receive ARP.[43]

4.3 | Other outcomes

4.3.1 | Further augmentation

Many studies of ARP have found ridge shrinkage to be greatest in the coronal area.[9,11,12,24,33,40] The shrinkage in the present study resulted in a ridge width of 4.4 ± 2.0 mm in group PC and 4.7 ± 1.8 mm in group SC at BW_1. Such widths are not sufficient to support the implant, and as further bone augmentation was needed at about half of the sites (46.2% in group PC and 53.3% in group SC). Such might be derived from the vertical position of the implant. Deep implant placement with respect to the periodontal attachment of the adjacent teeth was avoided because all participants in the present study were periodontitis patients. It is recommendable that patients should be notified of this non-negligible frequency prior to ARP.

4.3.2 | Patient discomfort level

Regarding patient discomfort level, group PC presented higher VAS values than group SC without a significant difference (3.9 ± 2.8 vs. 2.4 ± 2.4), which was not consistent with the findings of Engler-Hamm et al.[11] That study investigated the effects of PC for minimally damaged premolar and molar sites, and found significantly greater discomfort levels in the ARP group with PC. In the present study, all patients underwent flap reflection, thorough degranulation and overbuilding of bone substitute material. Those procedures might cause high discomfort levels in some patients irrespective of PC, suggesting that the response of the patient differs depending on the extent of socket destruction.

4.4 | Primary wound closure for ARP

The frequency of wound dehiscence in the present study indicates the difficulty of achieving successful PC in ARP. Even though PC was achieved at the time of ARP, 61.5% of the patients (8 out of 13) experienced wound dehiscence afterward. PC in ARP entails one or two vertical releasing incisions and suturing of the flaps of nonlinear margin (due to socket entrance), which appears to increase surgical difficulty. Especially, more extended downgrowth of junctional epithelium might be presented in periodontally damaged sockets, preventing approximation between connective tissue areas. Thus, a more careful surgical technique is needed to perform PC for ARP. In other studies, various percentages of wound dehiscence (or membrane exposure) were noted: 0% (0 out of 12 sites),[10] 12.5% (4 out of 32 patients),[44] and 45.5% (5 out of 11 sites).[45]

4.5 | Limitation

This study had some limitations. First, most sites in group PC presented wound dehiscence. Even though this finding can be considered as one of the results of the treatment, unwanted wound dehiscence is mainly mandated to use a full analysis set, not a per protocol set. Second, the stability of augmented bone could not be standardized. An in vitro study using pig jaws demonstrated bone augmentation without stabilization had reduced augmented dimensions even immediately after flap closure.[46] Other bone substitute materials with improved dimensional stability (e.g., soft-type block) and bone tacks may help increase wound stability.[47,48] Third, sample size was small.

5 | CONCLUSION

For periodontally damaged sockets, ARPs with and without PC led to similar new bone formation, hard-tissue changes, patient-reported outcomes, and additional augmentation frequencies. However, one should consider the difficulty of achieving PC predictably when performing ARP. To ensure long-term success, extended follow-up is required.

AUTHOR CONTRIBUTIONS

Gil-Jong Seo: Data analysis/interpretation; drafting article. **Hyun-Chang Lim**: Concept/design; drafting article. **Dong-Wook Chang**: Concept/design; critical revision of article. **Ji-Youn Hong**: Data analysis/interpretation. **Seung-Il Shin**: Drafting article. **Gyutae Kim**: Data collection; data analysis/interpretation; **Seung-Yun Shin**: Concept/design; critical revision of article, funding acquisition.

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CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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SUPPORTING INFORMATION

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