Three-dimensional Printed Polycaprolactone- biphasic Calcium Phosphate Scaffolds for Alveolar Ridge Preservation: A Clinical Study

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Abstract

The efficacy of root-form three-dimensional printed polycaprolactone–30% biphasic calcium phosphate scaffolds (PCL-30%BCP TDP) for alveolar ridge preservation (ARP) was assessed in fifteen fresh extraction sockets. In groups, A and B, the sockets were filled with the PCL-30%BCP TDP scaffolds and commercial root-form pure PCL scaffolds, respectively. In group C, the sockets were left empty (n=5/group). All sites were sealed with an absorbable collagen matrix. The dimensional change of each socket was demonstrated by the difference in the percentage of the distance of each reference line on cone beam computed tomography images taken immediately and five months after ARP. The socket wounds of all groups spontaneously healed without signs of foreign body reactions and infection. Slight wound dehiscence was detected in one case of group A and two cases of group B during the follow-up period. However, the wounds completely healed after trimming the exposed parts of the scaffolds. All implants were successfully installed with primary stability. The radiographic result demonstrated that the greatest dimensional change of the crestal bone was found in group C followed by group B and group A respectively ($p>0.05$). In conclusion, the PCL-30%BCP TDP scaffold was effectively used for ARP. It could maintain the dimension of the socket bone after tooth extraction.

Keywords**:** *Scaffold, Polycaprolactone, Biphasic Calcium Phosphate, Alveolar Ridge Preservation, 3D Printed*

1. Introduction

Dental implantation is a preferred option for supporting fixed and removable dental prostheses. Successful implant placement depends on having good bone quality with sufficient height and thickness. However, inadequate bone volume is often a result of rapid resorption of tooth socket-bone following tooth extraction, which makes it challenging to place dental implants to achieve optimal stability and aesthetics. Alveolar ridge preservation (ARP) is a procedure for preventing that resorption process by immediately placing some volume-maintaining materials into the sockets after tooth extraction. For many years, several bone substitutes have been used for the procedure. Autogenous bone grafting has long been considered the gold standard, but it comes with a significant increase in patient morbidity, whereas xenogeneic and allogeneic bone grafts such as bovine bone and freeze-dried bone are still concerned about the risk of disease transmission from different species and patient acceptance. Synthetic biodegradable scaffolds are a new alternative to conventional bone grafts. The researchers from the Cranio-Maxillofacial Hard Tissue Engineering Center (CTEC), Faculty of Dentistry, Prince of Songkla University, had developed two techniques for the fabrication of the scaffolds, including Melt Stretching and Multilayer Deposition (MSMD) and Melt Stretching and Compression Molding (MSCM). Polycaprolactone (PCL)-biphasic calcium phosphate (BCP) scaffolds were successfully fabricated using those methods. PCL is a bioresorbable polymer that has been approved by the U.S. Food and Drug Administration (FDA) for fabricated drug delivery and implanted medical devices. BCP is a composition of β-tricalcium phosphate and hydroxyapatite. It is known as a bioactive material due to the releasing ability of calcium and phosphate ions, which are essential for new bone formation during its degradation. The physical and biological properties of the scaffolds were intensively assessed in both in vitro and in vivo experiments (Rittipakorn et al., 2022; Thuaksuban et al., 2016; Thuaksuban, Monmaturapoj, et al., 2018; Thuaksuban et al., 2011; Thuaksuban et al., 2015; Thuaksuban et al., 2013; Thuaksuban, Pannak, et al., 2018). Regarding the techniques, the BCP particles could be used as the filler in the PCL-based scaffolds up to 30%. The architecture and surface properties of the scaffolds proved to be suitable for supporting new bone formation. In addition, the scaffolds could maintain releasing calcium and phosphate ions throughout the 30 days.

However, the devices and machines of those manufacturing processes were still prototypes that limited production capacity and had batch-to-batch variations. Three-dimensional (3D) printing technologies could overcome those limitations and fabricate bone substitute scaffolds with precise and controllable architectures. Regarding our current study, the 3D-printed (TDP) scaffolds were composed of PCL and BCP in a ratio of 70:30 by weight (PCL-30%BCP) (Supphaprasitt et al., 2022). The results indicated that the scaffolds had good biocompatibility and mechanical properties. In rat models, new bone regeneration was found within the interconnecting spaces of the scaffolds from week onwards, when they were filled into the critical size calvarial defects. Regarding the review literature, there was only one preliminary clinical study that fabricated pure PCL TDP scaffolds for that purpose. The result demonstrated that tooth sockets that were filled with the scaffolds had significantly less bone resorption when compared with untreated sockets. (Goh et al., 2015).

In this clinical study, the root-form PCL-30%BCP TDP scaffolds were explicitly fabricated for ARP. The efficacy of the scaffolds for ARP was compared with that of the commercial pure PCL TDP scaffolds.

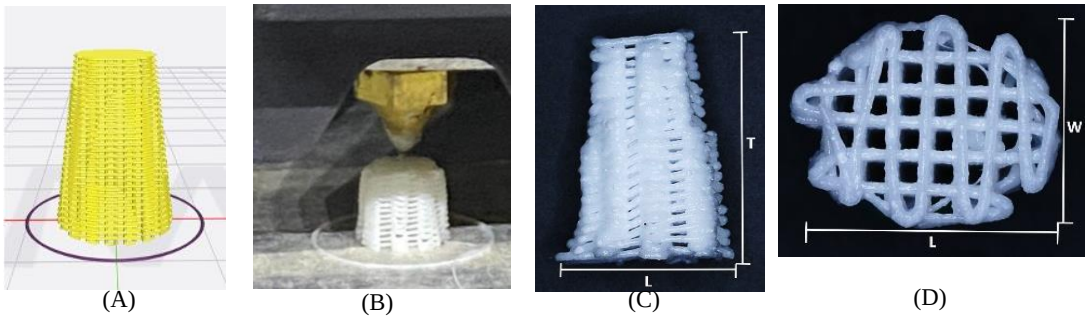
2. Objective

To compare clinical outcomes and dimensional changes of the alveolar ridges after the ARP procedures using the PCL-30%BCP TDP scaffolds and the commercial pure PCL TDP scaffolds.

3. Materials and Methods

3.1 Fabrication of the PCL-30%BCP TDP scaffold

The PCL pellets (Purasorb PC12, Mn 79,760, Viscometry 1.0 – 1.3 dl/g) were purchased from Corbion, Netherlands. The BCP particles (HA/TCP= 30/70 %, particle size < 75 µm) were supplied by the National Metal and Materials Technology Center (MTEC), Pathumthani, Thailand. The fabrication processes were performed in an ISO13485-certified clean room. The PCL pellets and the BCP particles were mixed in the ratios of PCL: BCP at 70:30 by weight in the chamber of the melting-extruding machine. The homogenous PCL-BCP blend was made by stirring at 140 °C, and then the blend was extruded through the nozzle tip of the machine to form a filament of 1.75 mm in diameter. Afterwards, the filaments were stocked for fabricating the scaffolds. To fabricate the root-form scaffold, the stocked filament was loaded into the 3-D printer (RAISE-3D E2, Raise-3D Technologies Inc., USA) and extruded through the nozzle tip of the machine as a grid pattern of filament lines with an average space area of 500 µm^2 and 0◦/ 90◦ to each lay-down layer. Figure 1 demonstrates the scaffold fabrication process, A: preview architectures of the scaffold, B: the printing process, C and D: dimensions of the root-form scaffold, length (L) 9 mm, width (W) 7 mm, and thickness (T) 11 mm. The scaffolds were kept in sterilization pouches, and the packaging was sterilized using gamma irradiation at 25 KGy 2 weeks before the experiments.



(A) (B) (C) (D)

Figure 1 The process of fabricating the scaffold

3.2 Patients and Study Design

The G-power software was used for calculating sample size based on the results of similar research (Goh et al., 2015). Therefore, the total sample size was 12, which was divided into three groups of four. To compensate for the 25% dropout rate, one subject was added to each group, resulting in five samples per

group. The study protocol was approved by the ethics committee, Faculty of Dentistry, Prince of Songkla University (Cert: EC6512-049). Fifteen volunteers enrolled from the Oral & Maxillofacial Surgery clinic, Faculty of Dentistry, Prince of Songkla University were the patients who were planned to extract unrestorable premolar or molar teeth followed by dental implantation. Inclusion criteria included age above 20 years old, American Society of Anesthesiology (ASA) classification I-II and having no infection of the extraction sites. Exclusion criteria included systemic diseases that contribute to infection, such as diabetes or immunodeficiency, smoking habit, previous radiotherapy or chemotherapy, and long-term taking bisphosphonate or steroids. Informed consent forms for participation in the study must be accepted and signed by the patients prior to the experiments. Patient confidentiality was maintained for the entire experiment and report. The prospective randomized controlled trial comprised three groups including Group A: the sockets were filled with the root-form PCL-30%BCP TDP scaffolds; Group B: the sockets were filled with the root-form pure PCL TDP scaffold (Osteoplug® PC21, Osteopore International, Singapore), and Group C (control): the sockets were left empty (n=5/group). The first cone beam computed tomography (CBCT) was taken on day 0 after tooth extraction for baseline, and the second CBCT was taken five months later prior to the placement of dental implants for evaluating bone quality and selecting the dimensions of the implants. The final restoration was performed within three months after the implantation.

3.3 Pre-operative Procedure

Prior to the ARP operations, impressions of the areas of the tooth extraction were taken using alginate material (Kromopan, Lascod S.p.A., Florence, Italy) to make study models. Acrylic stents with extensions of acrylic plates involving mesial and distal adjacent teeth were made. Cylinder reference slots on the buccal, mid-crestal, and lingual surfaces of each stent were created using a round bur. Gutta-percha material was loaded to fill up the slots, and flowable resin composite (3M ESPE, USA) was relined on the entire bottom surface of the stent to create radiopaque reference planes on the images. The stents were inserted during the CBCT images as a reference for measuring the dimensional changes of the alveolar ridges.

3.4 Surgical procedures

3.4.1 ARP

All surgical procedures were performed by one oral and maxillofacial surgeon. For each patient, local anesthesia with 4% Articaine hydrochloride with epinephrine 1: 100,000 (Septanest, Septodont, France) was administered for an inferior alveolar nerve block or local infiltration. Atraumatic extraction was applied, and tooth-sectioning was performed in the case of difficult extraction to preserve the surrounding alveolar bone. After extraction, the tooth socket was curetted and irrigated, and then bleeding was stopped by gauze packing. In groups, A and B, the scaffolds were trimmed using a scalpel to fit the sizes of the extraction sockets. The scaffolds of each group were filled into the sockets at a level of 1 mm below the crests of the socket walls. In Group C, the extraction sockets were left empty. All extraction wounds were sealed with absorbable collagen matrix (Zimmer® Collagen Tape, Zimvie, USA) and secured with a Vicryl 4/0 absorbable suture. All patients were prescribed antibiotics (Amoxicillin 500 mg, t.i.d. pc or Roxithromycin 150 mg, bid. ac in case of allergy to penicillin), analgesic drugs (Ibuprofen 400 mg, t.i.d. pc, or paracetamol 500 mg, q 6 hr. prn for pain if allergy to NSAID) and antiseptic mouth wash (0.12% chlorhexidine, twice daily) for seven days. The sutures were removed two weeks after the surgeries. The wound healing and any complications were assessed and recorded descriptively at the recall time points.

3.4.2 Dental implant placement and assessment

The implant fixtures were installed in all patients five months after the tooth extractions. For each patient, the second CBCT was taken to evaluate the bone quality and anatomical landmarks of the implanted site and to select the dimensions of the implant. In operation, after the local anaesthesia, a para-cristal gingival flap was created at the site. Bone specimens of the middle portion of the socket were collected in cylinder shapes (3 mm in diameter and 6 mm in length) using a trephine bur (Meisinger, Germany). The specimen was fixed in 10% formalin for histological assessment. Afterwards, the dental implant (Straumann bone level, Basel, Switzerland) was placed as per standard protocol. The wound was closed by suturing with the absorbable suture.

3.5 Measuring the dimensional change of the alveolar ridges

Two investigators analysed all measurable data. Intra-examiner and inter-examiner agreements were evaluated using the intraclass correlation coefficient (ICC). For the intra-examiner, reproducibility measurements were obtained at two different time points, with a minimum interval of 72 hours, yielding scores ranging from 0.86 to 0.96. For the inter-examiners, reproducibility data varied from 0.88 to 0.97 over seven days and from 0.81 to 0.94 over 28 days. The radiographic images were taken using the CBCT machine (3D Accuitomo 170, J Morita, Kyoto, Japan) with a setting of 90 kvp, 7.0 mA, and 17.5 sec scan time. The subjects' heads were stabilized using ear rods and positioned according to the Frankfort horizontal plane relative to the floor. Resorption of the socket bone was assessed by measuring the change of the in length of the four reference lines between the first and second CBCT using analysis software (OneVolume Viewer, J. Morita, Japan). Figure 2 shows the method for measuring the dimensional change of the alveolar ridge using the CBCT. A: The custom-made acrylic stent was inserted on the extraction site prior to taking the CBCT images. B and C: Radio-opaque reference slots in the stent that were seen in the images. Three mid-crestal references (a yellow circle) were used as the main references. Only the references along the middle section (green lines) were used for the measurement in the study. D: Four reference lines of the middle section were used for the measurement (bc=buccal crest, mp=middle portion, lc-lingual crest, cw=crestal width). The first reference line (blue line) was created parallel to the axis of the middle slot, and the second reference (yellow line) line is drawn perpendicular to the first line, and along the plan of the resin composite. The third reference lines (red arrows) are drawn perpendicular to the second line and parallel to the first line until they contact the highest points of the buccal and lingual ridges. The fourth reference line (green line) is drawn, connecting the third reference line. The same positions of the sections between the time points were controlled by the radiopaque gutta-percha slots in the stent of each section. Changes in the distances between the time points were calculated in percentages. During the collection of the data, the treatment groups were blinded, and code-breaking was performed after completing the final statistical analysis.

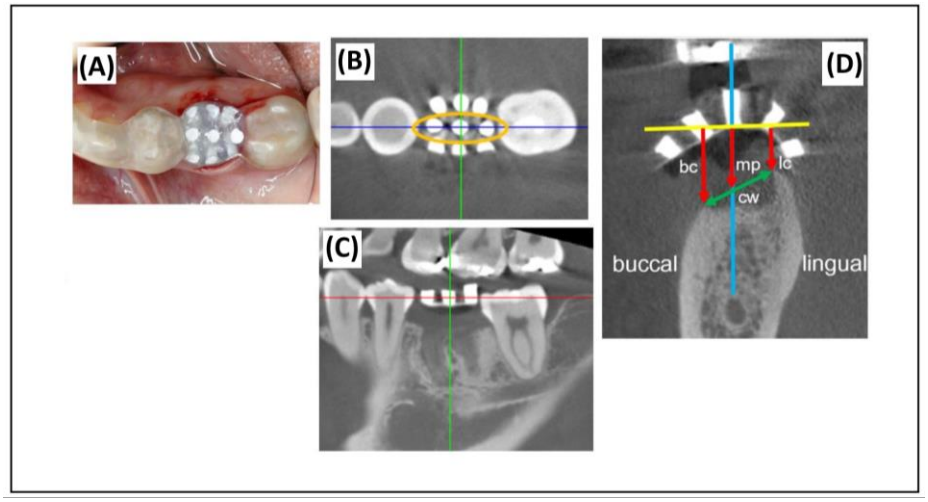


Figure 2 The method for measuring the dimensional change of the alveolar ridge using the CBCT

3.6 Histological assessment

After the fixation process, the bone specimens were embedded in paraffin. Longitudinal serial 5 µm-thick sections were cut along their midline and stained with Hematoxylin and Eosin (H&E). Afterwards, the section slides were scanned using a slide scanner (ScanScope, Aperio, USA) to become image files. The histological features of the specimens were descriptively evaluated.

3.7 Statistical analysis

The data was analyzed using SPSS version 14 (IBM Corporation, Armonk, NY, USA). The clinical evaluation and the histological features of the grafted sites were assessed descriptively. One-way Analysis of Variance (ANOVA) followed by Tukey's HSD was applied to compare the differences in the radiographic parameters among the groups and the time points. The level of statistical significance was set at a $p< 0.05$.

4. Results

4.1 Clinical assessment

The demographic data of the patients is shown in Table 1. Fifteen patients, including seven males and eight females, with an average age of 45.67 ± 17.35 years old, were enrolled. There were nine sockets in the mandible (60%) and six in the maxilla (40%). No statistical difference in age, gender, location of the tooth, tooth type and socket classification among the three groups was detected at baseline ($p > .05$). All patients tolerated the operation well, and they were healthy during the observation period. The surgical wounds of all groups spontaneously healed without signs of infection and foreign bodyreactions. During the follow-up period, slight wound dehiscence was detected in one group A patient at two weeks and two patients in group B at one month and four months, respectively. Some parts of the exposed materials were trimmed or removed to accelerate the soft tissue healing. Five months after the tooth extraction, the soft tissue of all groups completely healed, as seen in Figure 3. A, D, and G: The soft tissue of all groups completely healed. B and E: remnants of the scaffolds of groups A and B were seen integrating with the surrounding bone (arrows). C, F, I: All implants could be installed with good primary stability. In group B, additional bone grafts were required in 2 cases for correcting peri-implant bone defects. In Group C, buccal bone collapse was observed in most cases. Augmentation of soft tissue contours using connective tissue grafts was performed to compensate for the compromised bone contours in 2 cases.

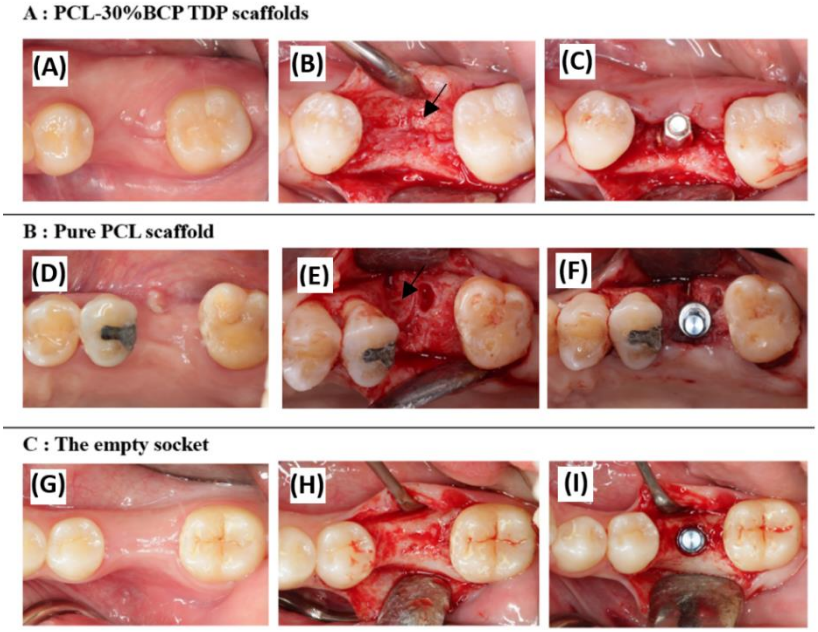


Figure 3 The clinical features in the re-entry visits five months after extraction

Table 1 The demographic data of the patients

Parameters	Group A (n=5)	Group B (n=5)	Group C (n=5)	Total (n=15)	*p-value*
Age, mean ± SD (y)	48±16.87	43.8±19.99	45.2±18.91	45.67±17.35	0.937
Gender, N (%) Male Female	2(40%) 3(60%)	1(20%) 4(80%)	4(80%) 1(20%)	7(46.67%) 8(53.33%)	0.178
Location (%) Maxillary Mandibular	2(40%) 3(60%)	3(60%) 2(40%)	1(20%) 4(80%)	6(40%) 9(60%)	0.493
Tooth types (%) Premolar Molar	1(20%) 4(80%)	1(20%) 4(80%)	1(20%) 4(80%)	3(20%) 12(80%)	1.000
Socket classification I IIa	3(60%) 2(40%)	3(60%) 2(40%)	4(80%) 1(20%)	10(66.67%) 5(33.33%)	0.783

4.2 Dimensional change of the alveolar ridges

Changes in the lengths of the reference lines between the first (baseline) and second CBCT images indicated the dimensional change of the alveolar ridges. Table 2 shows the distances in millimetres and the differences in millimetres (mm) and percentages. The baseline measurements of the four reference lines revealed no significant difference among the groups. It was found that group C had the highest average distance changes of all reference lines, whereas groups A and B demonstrated minimal changes. The changes were more obvious in the buccal bone crests, with a tendency to decrease in the middle portions and lingual crests. Interestingly, in groups A and B, reducing the distances of the lingual crest reference lines in the second image would indicate potential new bone gain. In addition, a reduction of the crestal width would imply crestal bone remodeling. In Figure 4, the bar graph demonstrates the change in the reference lines of the middle section between the two time points. The highest resorption was detected at the buccal crestal bone, followed by the middle portion and the lingual crest, respectively. The highest resorption of the crestal bone was detected in the control group, followed by groups B and A respectively. However, there was no statistical difference among the groups (p>0.05).

Table 2 The dimensional change of the alveolar ridges

Reference lines		Group A	Group C	Group C	*P* value
Middle portion (mp)	1st CBCT (mm)	4.25±0.79	5.58±3.08	4.91±1.89	0.628
	2nd CBCT (mm)	4.40±0.58	5.96±1.59	6.14±1.33	
	Difference (mm)	0.148±0.85	0.372±2.62	1.236±1.10	0.585
	Mean resorption (%)	5.64%	29.85%	40.74%	
	P value	0.717	0.767	0.066	
Buccal crest (bc)	1st CBCT (mm)	3.78±0.61	4.17±1.00	5.49±2.98	0.342
	2nd CBCT (mm)	4.40±0.43	5.55±0.93	7.48±3.53	
	Difference (mm)	0.620±0.75	1.37±1.66	1.99±1.67	0.347
	Mean resorption (%)	19.01%	43.99%	80.17%	
	P value	0.140	0.139	0.056	
Lingual crest (lc)	1st CBCT (mm)	4.37±1.39	6.18±4.55	4.13±1.23	0.480
	2nd CBCT (mm)	4.25±1.08	6.05±2.39	5.39±1.41	
	Difference (mm)	-0.124±0.99	-0.13±3.62	1.26±0.75	0.536
	Mean resorption (%)	0.22%	38.08%	32.96%	
	P value	0.794	0.939	0.020*	
Crestal width (cw)	1st CBCT (mm)	10.87±2.28	10.97±2.34	11.17±2.46	0.979
	2nd CBCT (mm)	8.57±2.83	8.18±1.11	7.64±4.61	
	Difference (mm)	-2.30±1.53	-2.80±1.71	-3.53±2.53	0.622
	Mean resorption (%)	-21.95%	-23.82%	-35.16%	
	P value	0.028*	0.022*	0.036*	

*Statistically significant ($p < 0.05$)

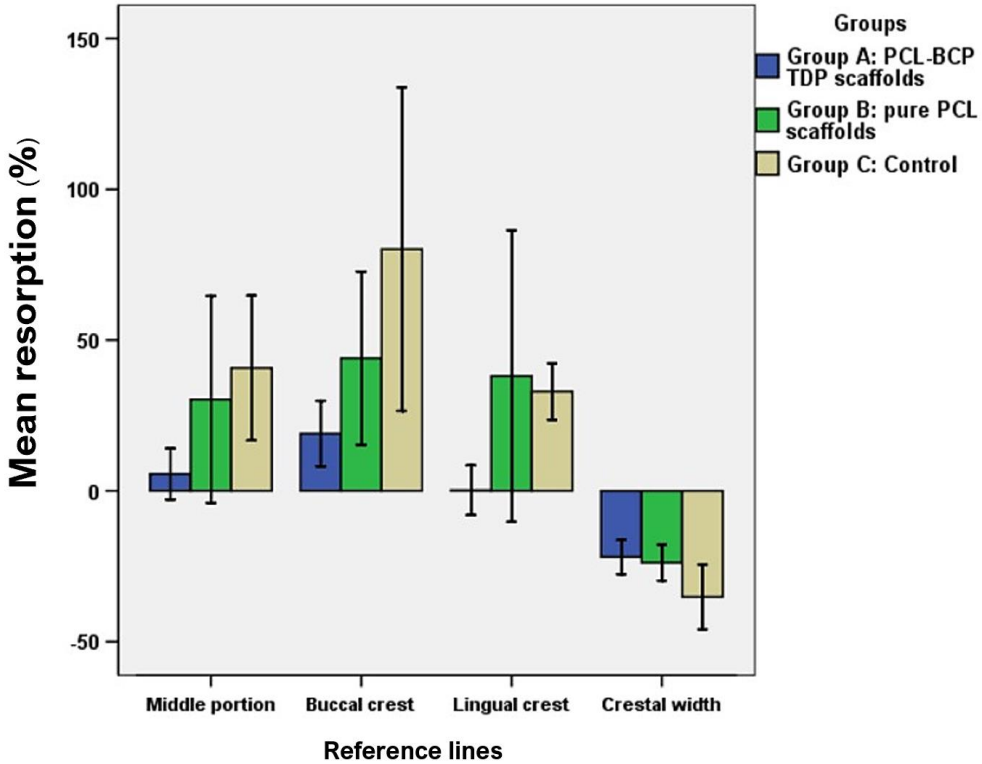


Figure 4 The change of the reference lines in the middle section between the first and second CBCT images

4.3 Histological assessment

The histological features of the specimens of groups A and B are demonstrated in Figure 5. The scaffolds of both groups are seen as empty spaces due to the slide processing. Newly formed bone (NB) is surrounded by dense connective tissue, and some parts of the scaffolds (SC) are seen. In group C, greater connective tissue and less newly formed bone were detected compared with those of groups A and B.

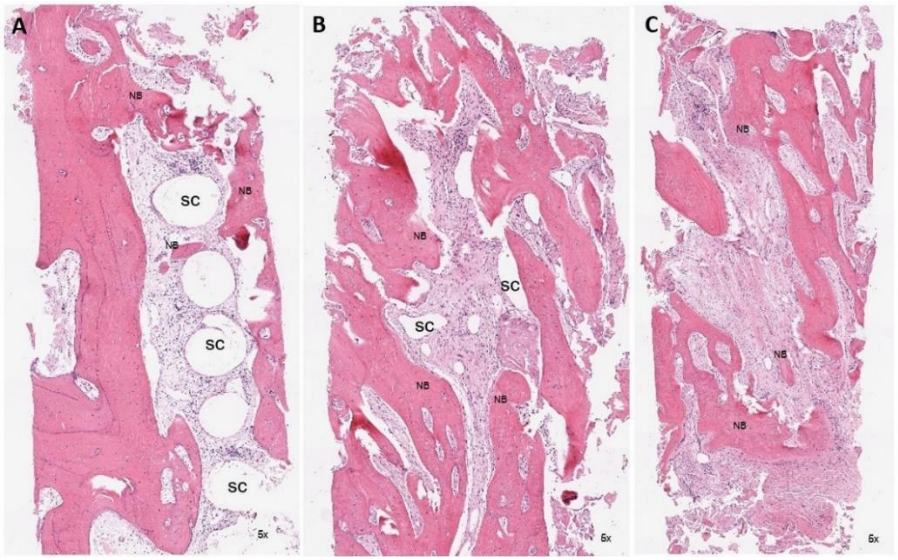


Figure 5 The histological features of group A (A), group B (B) and group C (C)

5. Discussion

This study introduced the alternative technique of using a synthetic scaffold instead of conventional particulate bone grafts for the ARP procedure. One major drawback of those materials, which include ceramic and xenogeneic particles, is their lack of self-volume maintenance. As a result, they require rigid barrier membranes or mesh trays to hold their volume, especially in cases of repairing one- and two-wall bone defects or bone augmentation. In this study, one of the clinical applications of the PCL-30%BCP TDP scaffolds for ARP was evaluated. The PCL-30%BCP TDP scaffolds have several advantages over particulate bone grafts. Firstly, the architecture of the scaffolds is reproducible, and they can be customized to fit into the defects using data from CT. Secondly, although the root form scaffolds have pre-formed shapes, they are easily trimmed to fit the tooth extraction site using basic surgical scissors or blades. Thirdly, unlike particulate bone grafts, the scaffold is a self-volume maintainer that can be used for repairing one and two-wall bone defects or bone augmentation without additional rigid membrane support. Regarding the fabrication process, the PCL-BCP filaments, which had been stocked for fabricating 3D scaffolds using the MSMD and MSCM techniques, could be adapted well for the TDP technique. The design of the 3D printed scaffold was still based on the architecture and interconnecting pore structure of the MSMD scaffold. The scaffolds were designed to have a regular interconnecting pore system and a pore size of 500 µm to allow vessel and new bone regeneration (Thuaksuban et al., 2011).

In this clinical trial, the results of ARP using the PCL-30%BCP TDP scaffolds were assessed over 5 months. Regarding the physiologic process of socket remodeling after tooth extraction, the highest resorption usually occurs at the crestal parts in the socket (Schropp et al., 2003). Therefore, the study introduced a simple method for measuring the change of the crestal contours of the alveolar socket bone using the CBCT images. Instead of cast-based measurement, which requires high-cost scanning software, using the custom-made surgical stent, which had the radiopaque references, was the effective re-measurable method for monitoring the changing process of ridge resorption. Five radiopaque reference slots in each stent were useful for adjusting the axes of the post-operative image and selecting the same coronal cut as the pre-operative image. The main references, including the radiopaque mid-crestal slot and plane on the image, could increase the accuracy of the second repeating measurement. In addition, the stents could be used as surgical guides for the implant installation. Regarding the result, the empty sockets had the highest crestal resorption, followed by those that were filled with the pure PCL and PCL-BCP TDP scaffolds, respectively. The dimensional changes of the buccal crest, middle portion, and lingual crest would indicate vertical bone resorption, while the changes of the crestal width would imply horizontal bone resorption. The vertical reduction of the buccal bone crests in the PCL-30%BCP TDP scaffold and the pure PCL TDP scaffolds was found to be 0.620±0.75 mm and 1.37±1.66 mm respectively. Additionally, horizontal reduction of the alveolar ridge width in the groups of PCL-30%BCP TDP scaffold and the pure PCL TDP scaffolds was 2.30±1.53 mm and 2.80±1.71 mm, respectively. These findings corresponded to the results of the previous studies (Avila-Ortiz et al., 2019; Bassir et al., 2018; MacBeth et al., 2017) that reported vertical reduction of buccal bone of the ARP-treated sites in the range of 0.79-1.72 mm and horizontal reduction of ridge width in the range of 0.73-2.96 mm. This study also demonstrated that the efficacy of socket preservation of the PCL-BCP TDP scaffolds was superior to that of the pure PCL scaffolds. It would be due to the bioactive BCP filler in the PCL-based scaffolds. The material can be degraded, releasing calcium and phosphate ions and producing carbonate apatite layers on its surfaces that are essential for promoting new bone formation (Thuaksuban et al., 2016; Thuaksuban et al., 2018). During the observation period, the material-filled socket wounds could heal without signs of foreign body reaction and infection, even if some parts of the scaffolds were exposed to the oral environment. It supported the claim that the scaffolds of both groups were biocompatible and safe for clinical use. Exposure to the scaffolds was possible due to two factors: scaffold swelling and surgical technique. By observation, the exposed filaments of the scaffolds seem to be swelling due to absorbing oral fluid. This phenomenon would reveal the degradation behavior of PCL in humans. Theoretically, the degradation of PCL starts through the process of autocatalysis with hydrolytic chain scission of ester linkages (Lam et al., 2009; Yeo et al., 2008). Afterwards, diffusion of water into inner portions causes swelling and starting bulk hydrolysis until entering the late stage of weight loss or the major phase of degradation. Therefore, it implied that the scaffolds still did not enter their major degradation phase 5 months after implantation. In addition, it would be recommended that the superior aspects of scaffolds should be below the crestal bone about 1.5–2 mm to prevent post-operative scaffold exposure. In the re-entry visits 5 months post-operation, remnants of the scaffolds remained in the healing socket wound. This is due

to the slow degradation of the major component of PCL in the scaffolds. In principle, the composition of BCP filler in the PCL-based scaffolds is hypothesized to accelerate their degradation rate. Regarding our previous rat models (Thuaksuban et al., 2018), the scaffolds had a degradation rate of 30.06 ± 10.48 % within 3 months. However, all implants were successfully installed, and even the remnants of the scaffolds remained in the positions of the implant placement. In addition, histological images supported the idea that the scaffolds would act as frameworks for supporting newly formed bone within the sockets. Regarding those properties, the scaffold was effectively used for ARP in the cases that were planned for dental implantation within 6 months post-tooth extraction. However, further study should assess whether the remnants of the materials will affect peri-implant bone after the functions of the implants using CBCT and measuring implant stability. In addition, a larger number of patients should be assessed. These will provide a more comprehensive understanding of the outcomes of ARP using the PCL-30%BCP TDP scaffolds.

6. Conclusion

The PCL-30%BCP TDP scaffold was effectively used for ARP. It could maintain the dimension of the socket bone after tooth extraction.

7. Acknowledgements

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