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ORIGINAL ARTICLE

Beta-tricalcium phosphate/type I collagen cones with or without a barrier membrane in human extraction socket healing: clinical, histologic, histomorphometric, and immunohistochemical evaluation

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Abstract The aim of this study was to investigate the healing of human extraction sockets filled with β-tricalcium phosphate and type I collagen (β-TCP/Clg) cones with or without a barrier membrane. Twenty patients were divided in two groups: (A) β-TCP/Clg non-membrane and (B) β-TCP/Clg + barrier membrane. Clinical examination and biopsies from the grafted sites were collected 9 months later. Bone samples were analyzed using histomorphometry and immunohistochemistry. The horizontal dimension of the alveolar ridge was significantly reduced 9 months after socket preservation in the non-membrane group. There was bone formation with no significant differences between the two groups in the areas occupied by new bone (A=42.4%; B=45.3%), marrow (A=42.7%; B=35.7%), or residual graft (A=9.7%; B=12.5%). Immunohistochemistry revealed osteonectin expression in both groups. Both groups demonstrated sufficient amounts of vital bone and socket morphology to support dental implant placement after the 9-month healing period. A future trial to evaluate the alveolar outcomes at an earlier 6-month time point rather than the 9 months used in this study would be of interest.

Keywords Socket preservation · Beta-tricalcium phosphate · Collagen type I · Barrier membrane · Histomorphometry · Immunohistochemistry

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Introduction

Immediately following tooth extraction, a blood clot develops in the alveolar socket and stimulates new bone growth inside the socket walls. However, this healing process never results in complete restitution of the original alveolar bone volume due to physiologic resorption [1]. Clinical, radiologic, and histologic studies have indicated that bony healing of extraction sites proceeds with external resorption and remodeling of the original socket walls with varying degrees of dimensional changes in both height and width of alveolar ridge [2, 3]. Reduction of bone in the horizontal socket dimension of approximately 50% takes place over 1 year of healing [4, 5]. In particular, the buccal bone plate, comprised almost entirely of bundle bone, demonstrates marked osteoclastic resorption in the coronal region of the socket [6, 7]. The early resorption of buccal bundle bone, which takes place during the first 8 weeks following extraction, proceeds with a marked reduction predominantly in the horizontal dimension [4, 8]. A reduction in vertical ridge height of 0.8 mm over a 3-month period also predominates on the buccal aspect [3].

Adequate volumes of alveolar bone which are close to the original dimensions of the alveolar process are necessary to provide favorable esthetics and successful long-term outcomes for dental implants. Therefore, preservation of extraction socket dimensions has been attempted by many investigators immediately following tooth extraction [9–13].

Autogenous bone is still considered as the gold standard for many osseous regeneration procedures [14, 15]. However, morbidity of donor sites, attempts at reduction in the number of surgical sites, and limitations in the amount of bone available are some objective reasons driving the development of bone substitutes to replace the use of autogenous bone [16, 17]. Alternative bone substitute materials should allow osteoblastic cells to grow both on their surfaces, have sufficient porosity to allow invasion of cells, and promote differentiation of the cells into active osteoblasts to allow for bone deposition onto the scaffold with its gradual replacement by native bone [18]. Barrier membranes guide bony healing by the exclusion of rapidly growing fibrous connective tissue from the bony defect to be regenerated by maintaining the space for bone regeneration [19]. Although the benefits from using membranes are well known, wound dehiscence may lead to early exposure, infection, and disintegration of the membrane followed by loss of bone at the grafted area [20–23]. Flap surgery to cover a barrier membrane may lead to the reduction of attached gingiva or soft tissue collapse into the defect with compromise of the esthetic outcomes [19, 23, 24].

Beta-tricalcium phosphate (β-TCP) is one popular alternative to autogenous bone. While β-TCP is known to be osteoconductive, it lacks growth factors and cellular components and therefore has no osteoinductive properties. β-TCP has also been shown to be resorbable and simultaneously capable of supporting new bone formation both in animal models [25–28] and in human trials [18, 29]. Bony regeneration has been reported with β-TCP without the use of barrier membranes in patients undergoing sinus floor elevation and mandibular cyst removal [30]. It is also possible to combine β-TCP with platelet-rich plasma or collagen to promote bone regeneration [31, 32].

Clinical data on the use of β-TCP in combination with type I collagen is lacking. The aim of this study was to evaluate human post-extraction socket preservation in patients treated with β-TCP + type I collagen (1) placed in an extraction socket without soft tissue closure or (2) with a barrier membrane and mucosal flap for soft tissue closure comparing clinical, histologic, histomorphometric, and immunohistochemical results.

Materials and methods

In this randomized study, 20 adult patients who required tooth extraction in either the maxilla or mandible were evaluated for post-extraction socket preservation in the canine–premolar–molar areas prior to dental implant placement. The 12 women and eight men were selected according to the following inclusion criteria: age between 20 and 55 years, ASA I status as classified by the American Society of Anesthesiologists, good oral hygiene, with indications for tooth extraction such as fracture of the tooth, non-vital tooth without the possibility of endodontic treatment and restoration, chronic periodontitis, endodontic treatment failure, and periodontal disease. Further inclusion criteria were: extraction sockets with four intact walls and an occlusion suitable for the planned prosthodontic treatment. The criteria for exclusion comprised the presence of any chronic systemic disease, allergy, medication given within 48 h pre-operatively, presence of purulent periodontal lesions as well as severe periodontal bone loss with a remaining alveolar height of less than 6 mm, history of chronic pain, pregnancy or nursing mothers, and inability to comply with the study protocol. The patients were non-smokers or had quit smoking for 2 months. A detailed explanation of the surgical treatment plan was given to each patient, and a written informed consent form was signed. The study was approved by the Ethical Committee of the Faculty of Dentistry, University of Belgrade (No. 22/2, 2006).

Atraumatic tooth extraction was performed for all patients under local anesthesia. The post-extraction sockets were thoroughly debrided. A single RTR Cone® containing

beta-tricalcium phosphate with type I collagen (β-TCP/Clg) (Septodont, Saint-Maur-des-Fosses, France) was placed into the resulting alveolar socket and trimmed to completely occupy the space from the crest of the alveolus to the apex of the socket. Surgical templates were made to help place the β-TCP/Clg cone into the center of the extraction socket and to guide future biopsy and implant placement. The 20 patients were randomly assigned to one of two groups for post-extraction socket preservation:

Group A (β-TCP/Clg) consisted of 11 patients in whom β-TCP/Clg cones were placed into the extraction sockets but were not covered with a barrier membrane and with a mucoperiosteal flap. The alloplastic material and socket opening was left to heal spontaneously (Fig. 1a–e)

Group B (β-TCP/Clg + membrane) consisted of nine patients in whom β-TCP/Clg cones were covered with a barrier membrane (BioGide®, Geistlich AG, Wolhusen, Switzerland) and with a mucoperiosteal flap (Fig. 2a–d).

Before placement of the β-TCP/Clg cones into the alveolar sockets in group A, limited intrasulcular incisions were made to elevate distal and mesial papillae and marginal gingiva. This exposure of crestal bone around the post-extraction sockets of both groups allowed the direct visualization and measurement of the crestal bone level. After cone placement, the papillae and marginal gingiva were secured with interrupted sutures to reduce the opening of the socket and the amount of exposed material. In group B, two vertical incisions and one horizontal intrasulcular incision were made along with periosteal scoring. This allowed the necessary mobility of the mucoperiosteal flap to completely cover the β-TCP/Clg

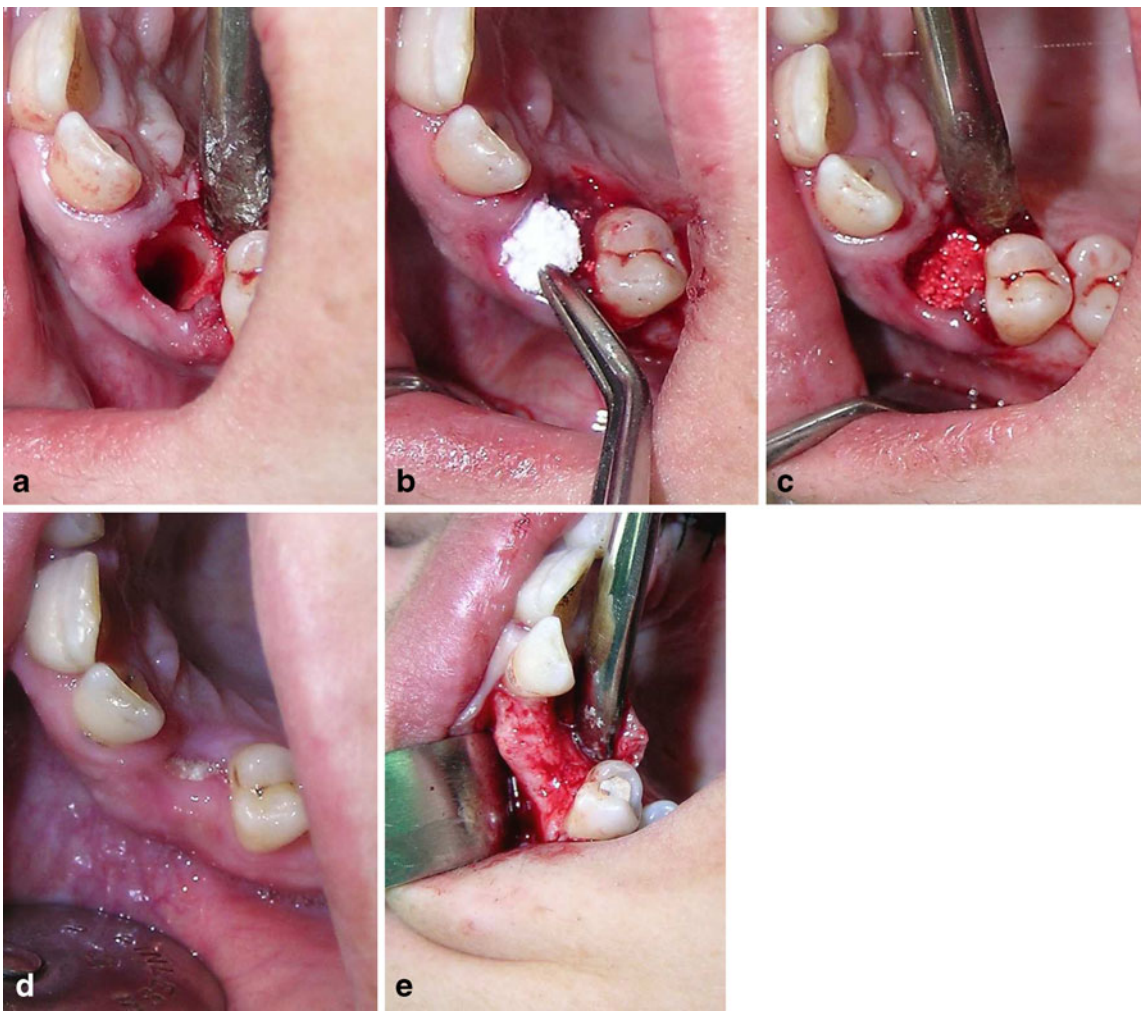

Fig. 1 **a** Extraction socket in β-TCP/Clg non-membrane group. **b** β-TCP type 1 collagen cone placed into socket. **c** β-TCP type 1 collagen cone trimmed to fit snugly into socket. **d** Healing of mucosa around non-membrane β-TCP type 1 collagen-filled socket at 1 week following placement. **e** Alveolar ridge exposed at biopsy and implant placement 9 months following socket preservation with β-TCP type 1 collagen without a barrier membrane

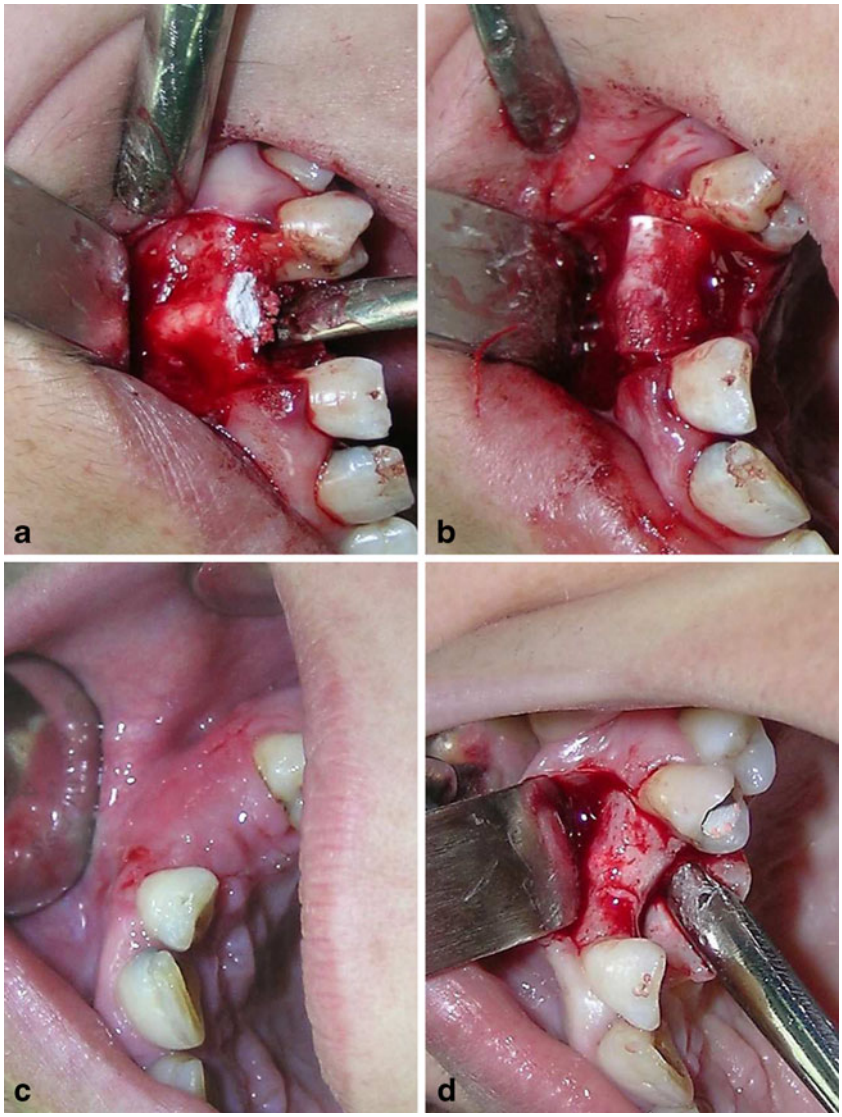

Fig. 2 **a**, **b** β-TCP type 1 collagen cone placed into socket in **b**. Resorbable collagen membrane covering the β- TCP type 1 collagen cone. **c** Healing of mucosa around membrane-covered β-TCP type 1 collagen-filled socket at 1 week following placement. **e** Alveolar ridge exposed at biopsy and implant placement 9 months following socket preservation with β-TCP type 1 collagen with a barrier membrane

cone material and barrier membrane at the socket opening using interrupted sutures.

A 7-day course of amoxicillin (Amiksicilin® 500 mg, Panfarma, Belgrade, Serbia) and ibuprofen (Brufen® 400 mg, Galenika, Belgrade, Serbia) as required was prescribed and detailed post-operative instructions were given to all patients. Sutures were removed at 7 days in both groups. The patients were regularly examined by the surgeon who performed the surgical procedure at days 3, 5, and 7 and then at 4 and 9 months post-operatively for detection of possible complications and side effects while periapical and panoramic radiographs were taken at 1 week and at 4 and 9 months following the placement of the alloplastic material. An independent surgeon not involved in the surgical procedure evaluated the healing of the sockets every 2 days until the socket opening completely closed.

The surgical sites were exposed after 9 months and a biopsy was performed using a trephine drill measuring 6 mm in length and 3 mm in diameter from the centers of the extraction sockets which were previously filled with β-TCP/Clg cones. The biopsies were guided by the surgical template used at the time of cone placement. Following the trephination, implants were placed using the same surgical template (Replace® NobelBiocare, Goteborg, Sweden).

The reduction of alveolar bone, measured at the cervical part of the socket, was determined before socket preservation and 9 months later using a periodontal probe and caliper in the following ways:

1. Distance between a line which connects the cemento-enamel junctions of the mesial and distal tooth, and crestal bone at the central point of the buccal and palatal sites (vertical dimension)
2. Distance between the central point of the buccal and palatal walls (horizontal dimension) at the level of crestal bone

Clinical measurements were used instead of X-rays in order to avoid possible magnification and angulation errors with periapical radiographs.

Other clinical observations included:

3. Duration of complete epithelization of the alveolar socket opening
4. Clinical characteristics of the grafted area at the time of implant placement
5. The length of the attached gingiva measured with dividers and a flexible ruler as the distance between the imagined line which connects the occlusal planes of the adjacent mesial and distal teeth and mucogingival margin
6. Untoward effects or local reactions as well as patient compliance were monitored during the follow-up period

Histologic and histomorphometric analyses were done on 15 bone biopsies (eight in group A and seven in group B). The trephines containing the bone were fixed in 10% neutral buffered formalin. The specimens were dehydrated with alcohol for 9 days. A non-decalcified method was used. The specimens were cut to a thickness of 150 μm on an EXAKT cutting/grinding system (EXAKT Technologies, Oklahoma City, OK, USA). The slides were then polished to a thickness of 45 μm and stained with Stevenel's blue and Van Gieson's picro fuchsine. All cores were examined under a microscope at the same magnification and photographed with a digital camera for further histomorphometric analysis. All measurements were completed using a combination of Adobe PhotoShop (Adobe System, Inc., San Jose, CA, USA) and the public domain NIH Image program (US National Institutes of Health' http://rsb.info.nih.gov/nih-image/). At least two slides of each core were evaluated to record the total area of the cores, percentage of new bone formation, and percentage of residual graft material.

Immunohistochemistry was performed on five bone samples (three in group A and two in group B) as the expense of immunohistochemically treated sections made it necessary for the authors to limit the number of sections to remain within a manageable budget. Sections which were 4-μm-thick and mounted on poly-L-lysine-coated glass slides were used. The slides were heated overnight at 37° C, deparaffinized, and hydrated in decreasing grades of alcohol solutions. Antigen retrieval was achieved by the heating slides with citrate-buffered solution in a microwave oven at two cycles of 5 min each. The sections were then incubated at 4°C in a humidified chamber with the primary antibody against osteonectin (clone NCL-O-NECTIN 15G12, Novocastra Co., UK) at a dilution of 1:20 overnight. A two-step technique was used for the secondary antibody (Envision, Dako, CA, USA). Diaminobenzidine was prepared as the chromogen and the slides were lightly counterstained with hematoxylin and mounted. For the negative control specimen, the primary antibody was omitted and replaced by tris-buffered saline solution.

Statistical analysis was performed using Sigma Stat software (3.1 Sigma Stat Software Inc., Richmond, CA, USA). A paired Student *t*-test was used for the statistical analysis of demographic and surgical data, changes of the alveolar ridge dimension between pre-operative and post-operative measurements at 9 months, and for histomorphometric analysis. For statistical analysis of the clinical characteristics of grafted area, ANOVA and chi-square tests were used. Mann–Whitney test was used to examine the changes of the vertical and horizontal dimensions between the two study groups. Comparisons were considered significant at $p<0.05$.

Results

There were no statistically significant differences in patient characteristics and surgical parameters between the two groups (Table 1). All implants achieved initial stability after placement. All extraction sites healed uneventfully and showed no signs of inflammation. Epithelial closure of the socket opening occurred approximately 3 weeks after placement of the material at the sites without membrane and flap surgery, while the reduction of attached gingiva was significant ($p=0.05$) in patients treated with β-TCP/Clg + membrane in comparison to the β-TCP/Clg non-membrane group of patients (Table 2).

Several clinical parameters were assessed following 9 months of healing at the time of implant placement (Table 2). There was continuity of the grafted area with the native bone at all sites. Two patients in the non-membrane group had fibrous adhesions at the cervical part of the previously preserved sockets. No suppuration or pathological lesions were seen at any of the grafted sites. There was bone-like drilling resistance during implant site preparation and resistance to hard probing of the newly formed bone in the sockets of both groups. The residual particles of implanted material were significantly more apparent in the β-TCP/Clg + membrane group when compared to the β-TCP/Clg non-membrane group ($p=0.03$).

The resorption of the alveolar ridge 9 months after socket preservation was mostly evident at the buccal plate of bone. There was a significant reduction of the horizontal dimension in β-TCP/Clg non-membrane-treated patients 9 months after socket preservation when compared to the horizontal dimension before treatment. Differences in vertical dimensions were not significant between the non-membrane and membrane groups at the 9-month time point although a slight vertical resorption was recorded at the

Table 1 Demographic and surgical data

Parameters	β-TCP/Clg	β-TCP/Clg + membrane	Significance
n	11	9	NS
Age (years)	49±15	46±13	NS
M/F	5/6	3/6	NS
Smoker/non-smoker	4/7	5/6	NS
Teeth			
Anterior/posterior	5/6	4/5	NS
Mandible/maxilla	8/3	4/5	NS
Diagnosis			
A/B/C/D	2/6/2/1	2/3/1/3	NS
Implants			
Diameter[a]	3.82±0.41	3.70±0.37	NS
Length[a]	12.1±1.5	11.9±1.6	NS

NS not significant, *M* male, *F* female, *A* periodontal disease, *B* non-vital tooth, *C* chronic periapical lesion, *D* fracture of tooth

[a] Values given as mean ± SD

palatal/lingual aspect than that at the buccal aspect in the group treated with membrane (Table 3).

All bone samples consisted of mineralized bone and bone marrow with trabecular bone (Fig. 3a, b). The cervical part of the bone samples in the non-membrane group contained bone marrow intersected by thin immature trabecular bone with woven and lammelar bone peripherally. Both groups were characterized by the presence of mineralized immature and lamellar bone in the apical areas. Trabecular bone was surrounded by osteoid which was lined by active osteoblasts or osteoblast-like cells. The accumulation of osteoblasts was also seen in the areas actively forming bone. Newly formed bone was characterized by irregular, large lacunae containing osteocytes. Both groups showed areas of new bone deposition associated with residual β-TCP particles with no fibrous tissue

Table 2 Time for complete epithelization of socket opening and clinical characteristics of grafted area at the time of implant placement

Characteristics	β-TCP/Clg	β-TCP/Clg + membrane	Significance
Epithelial closure of socket opening (day)[a]	19.1±4.7	/	
Visibility of particles (yes/no) (time of implant placement)	4/7	4/5	$p=0.03$
Continuity with native bone			
Yes	11	9	NS
No	0	0	
Fibrous adhesions			
Yes	2	0	NS
No	9	9	
Purulent discharge			
Yes	0	0	NS
No	11	9	
Drilling resistance (bone quality)			
Decreased resistance	4	2	NS
Bone-like resistance	7	7	
Probing resistance			
Hard	6	6	NS
Flexible	4	3	
Soft	1	0	
Pre-operative pathological lesions			
Yes	0	0	NS
No	11	9	
Reduction of attached gingiva			
Yes	0	9	$p=0.05$
No	11	0	

[a] Mean ± SD

Table 3 Changes of alveolar ridge dimension (mean ± SD)

Parameters	β-TCP/Clg	β-TCP/Clg + membrane	Significance
Horizontal dimension (mm)			
Pre-operative	7.88±2.33	7.39±2.00	p=0.518
9 months after	6.59±2.44	6.53±1.83	
Significance	p=0.007	p=0.098	
Vertical dimension/palatal/lingual aspect (mm)			
Pre-operative	3.00±1.25	3.00±1.85	p=0.101
9 months after	3.22±1.48	3.38±1.94	
Significance	p=0.225	p=0.520	
Vertical dimension/buccal aspect (mm)			
Pre-operative	3.10±1.45	3.19±1.69	p=0.721
9 months after	3.60±1.51	3.31±1.75	
Significance	p=0.138	p=0.849	

encapsulation or inflammatory cellular infiltration. Particles of resorbing β-TCP were dispersed and well incorporated into the newly mineralized bone and bone marrow. In some samples, new bone was noted inside the pores of the β-TCP material.

The histomorphometric results are summarized in Table 4. The addition of a membrane with a mucoperiosteal flap to cover the β-TCP/Clg cones did not demonstrate any statistically significant differences in any of the parameters of bone remodeling.

Osteonectin expression was mainly detected in differentiating osteoblasts or osteoblast-like cells lying over the newly formed bone in both the β-TCP/Clg non-membrane and β-TCP/Clg + membrane groups (Fig. 4). Some osteonectin-positive cells were also found in bone marrow and around the residual β-TCP particles.

Fig. 3 **a**, **b** Photomicrograph of a biopsy core in its entirety obtained 9 months after placement from **a** β-TCP/Clg + membrane group and **b** β-TCP/Clg non-membrane group. Both specimens contained newly mineralized bone and bone marrow (Stevenel's blue and Van Gieson's picro fuchsin stain; magnification, ×25)

Discussion

The results of this study demonstrate that dental implant placement was possible at extraction sites that were treated with β-TCP/Clg cones whether a barrier membrane was used or not. Biopsy specimens were harvested and dental implants were placed after a 9-month healing period in the present study. This healing period was chosen because it was the time point used in previously reported maxillary sinus and alveolar augmentation studies [33]. Cellular differentiation, augmentation material breakdown, and bony replacement were noted to be evident at the grafted sites largely preserving the dimensions of the alveolar ridge after 9 months of healing [33]. A shorter 6-month time point should be evaluated in the future.

The histological analysis of both the membrane- and non-membrane-treated groups showed large amounts of new bone formation consisting of woven bone, marrow, and lamellar bone after 9 months of healing. The sites that were grafted by β-TCP/Clg without a membrane demonstrated larger amounts of bone marrow at the most coronal region with lamellar bone peripherally compared to the membrane-treated group.

It was interesting to note that, in the non-membrane group, there was no evidence of fibrous tissue in-growth into the porous structure of β-TCP particles or into the bone marrow. Several possibilities may explain the apparent soft tissue blockade. Inhibition of fibroblastic proliferation by metabolites of degrading β-TCP and a local decrease in pH during the process of chemical dissolution of β-TCP particles can slow down or even block fibrous tissue formation, favoring bone regeneration [34, 35].

At the apical sites of bone samples, woven bone was mostly seen in conjunction with both lamellar bone and

Table 4 Histomorphometric analysis (%)

	β-TCP/Clg (n=8)	β-TCP/Clg + membrane (n=7)	Significance
New bone	42.4±14.6	45.3±14.5	p=0.714
Marrow	42.7±10.9	35.7±12.4	p=0.262
Residual graft	9.7±7.3	12.5±6.6	p=0.449
Fibrous tissue	4.4±3.6	6.4±5.2	p=0.392

Values given as mean ± SD

bone marrow. The histologic results of the non-membrane group indicate that the process of socket healing may be initiated from the apical and lateral regions of the extraction socket walls in agreement with observations from previous studies in which soft tissue closure was not performed [10, 36]. The periosteum did not contribute to the formation of new bone matrix in the extraction sockets [10] since the open sockets healed with gradual wound contracture and lateral epithelial overgrowth [6, 10, 37]. Conversely, the sites that were grafted with β-TCP/Clg + membrane demonstrated a more uniform bone structure both in the apical and in the coronal regions of the sockets.

Although the histological appearance at the apical and coronal portions of the bone samples differed between the membrane and non-membrane groups, the histomorphometric results were similar with an average of 45% and 42% of new bone and 36% and 43% of bone marrow in β-TCP/Clg + membrane and β-TCP/Clg, respectively. Similar

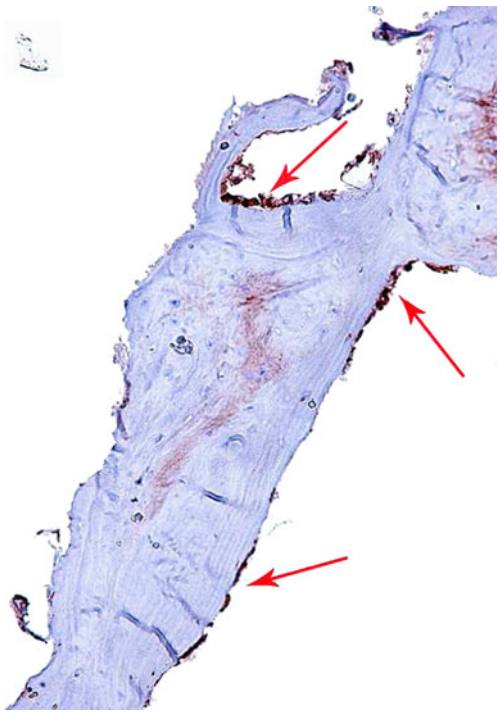

Fig. 4 Osteonectin-stained β-TCP/Clg non-membrane-treated socket at 9 months after socket preservation. Cells stained for osteonectin (*red arrows*) were seen close to the newly mineralized bone (immune staining; magnification, ×40)

histomorphometric results of new bone formation were reported by Szabó et al. [38] using β-TCP in patients undergoing sinus floor augmentation. The authors took the bone samples 6 months after augmentation from a lateral bone window which was not protected by a barrier membrane. The sites comprised newly formed lamellar bone (36.47%±6.9%). Simunek et al. [39] reported that 9 months of healing resulted in the appearance of newly formed vital bone with a wider trabecular structure (21.4% ±8.1%) and fibrovascular tissue (39.6%±4.8%). In the present study, both groups showed the presence of newly formed trabecular bone, lined with osteoid, and demonstrated that active bone formation was still occurring 9 months following socket preservation. The activity of osteoblasts, verified by immunohistochemistry, suggested that the remodeling of immature woven bone into lamellar bone at the grafted sites was still ongoing. A recent publication showed that the combination of β-TCP and type I collagen used for simple preservation of a maxillary extraction socket without a barrier membrane resulted in new bone formation 9 months after the procedure with 62.6% of mineralized bone and 21.1% of bone marrow [11]. β-TCP resorption occurs concurrently with new bone formation [40]. The degradation rate of porous β-TCP has been shown to depend not only on its porosity and pore size [40] but also on other factors, such as implantation site [35, 41], smoking habits [42], and defect size [43]. Horch et al. [43] reported 65% resorption of β-TCP 1 year after placement when used as bone substitute in large mandibular cystic defects, in alveolar clefts, and for maxillary sinus floor augmentations. Simunek et al. [39] reported that the mean graft area occupied by β-TCP was 39% 9 months after sinus augmentation procedures.

Osteonectin is a non-collagenous protein which is thought to be one regulator of bone metabolism. Osteonectin is a phosphorylated glycoprotein with a high affinity for type I collagen and hydroxyapatite, initiating mineralization and promoting mineral crystal formation [44, 45]. In this study, osteonectin expression was detected in differentiating osteoblasts or osteoblast-like cells overlying newly formed bone in both the β-TCP/Clg non-membrane and β-TCP/Clg + membrane groups while some osteonectin-positive cells were also found in the bone marrow and around residual β-TCP particles.

In contrast to the findings of previous studies which observed healing of larger bone defects, the current study showed that the preserved extraction sockets contained 9.7% and 12.5% residual graft in β-TCP/Clg non-membrane and β-TCP/Clg + membrane groups, respectively. One reason for such favorable results is the regeneration potential of the intact four-walled alveolar sockets common to both groups in this study [10, 23]. Both groups showed the residual particles of graft to be well incorporated into the newly mineralized bone as well as into the bone marrow and marginal osteoid [25]. The residual graft was mostly evident as dispersed particles resulting from the dissolution of the implanted material.

One of the most important goals of alveolar socket preservation is the prevention of the rapid reduction of buccal plate of bone. A variety of biomaterials have been introduced into extraction sockets in animal models in an effort to decrease the resorption of buccal bone without the use of barrier membranes and flap surgery [4, 7]. The buccal plate is composed of vulnerable bundle bone [4, 7]. Elevating the periosteum from buccal bone to create a mucoperiosteal flap compromises the blood supply of the exposed bone surface, leading to osteoclastic activity and bone resorption [8, 46].

The results of the present study have shown a significant reduction in horizontal dimension between the pre-operative value and the post-operative value at 9 months in the β-TCP/Clg non-membrane group, but no significant differences were observed in the vertical dimensions of the alveolar ridges between the membrane and non-membrane groups. A slight reduction of 0.38 mm was measured at the palatal/lingual aspect compared with a buccal aspect reduction of 0.12 mm in the membrane group which is not usually expected with the less vulnerable cortical palatal bone. However, these changes were less than 0.4 mm and not statistically significant. The vertical loss of the buccal bone plate is important since it seems to have major consequences for soft tissue stability [7]. When the buccal bone plate is resorbed, the soft tissues of the attached gingiva, marginal gingiva, and papillae will collapse to the new bone level, leading to dimensional changes which can be detrimental especially in the esthetic zone. Other studies have shown that the quantity of buccal bone resorption in both directions is more than 2 mm whether a barrier membrane is used or not [4, 47].

This randomized study of 20 grafted human extraction sockets showed that both β-TCP/Clg and β-TCP/Clg with a barrier membrane and mucoperiosteal flap produced vital bone sufficient to support subsequent dental implant placement after an observation period of 9 months. Both membrane and non-membrane groups exhibited a similar potential for bone healing. Clinical evaluation showed a significant difference in the presence of residual β-TCP particles and reduction of attached gingiva in the β-TCP/Clg + barrier membrane and flap surgery group compared with β-TCP/Clg non-membrane grafted sites. Future investigations to evaluate the alveolar dimensions using a 6-month time point rather than the 9-month healing period used in the current study would be of interest.

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Conflicts of interest The authors declare that they have no conflicts of interest.

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