Reconstruction of alveolar bone with 3D bioprinting PCL scaffold and β -TCP

Keunshuh Kim¹, Youngkyun Kim², Hyojung Lee¹, Shinyoung Park¹, Sungyeol Kim¹
¹Department of Periodontology, Section of Dentistry, Seoul National University Bundang Hospital, Seongnam-si, Gyeonggi-do, Korea
²Department of Oral and Maxillofacial Surgeons, Section of Dentistry, Seoul National University Bundang Hospital, Seongnam-si, Gyeonggi-do, Korea

Abstract

This study aimed to evaluate a customized polycaprolactone (PCL) scaffold fabricated using a 3D) bioprinting system for alveolar bone reconstruction in large animal model. In four beagle dogs, segmental bone defects were surgically created on the healed site after the extraction of premolars in the beagle mandible. The defect was examined by computed-tomography to design an ideal customized 3D PCL scaffold block to fit the defect site by rapid-prototyping. The PCL scaffolds were fabricated as narrow lattices (block (400/400)) or wide lattices (block (400/1200)). They were implanted into the alveolar bone defects according to the group. Histologically, both PCL blocks remained intact and support the defect space without soft tissue rupture. In addition, no inflammatory infiltrate were observed around the PCL blocks. New bone was formed around both blocks but pattern of new bone was different between them. Block (400/1200) allowed bone formation within the lattices whereas block (400/400) did not. However, both PCL blocks did not directly contact to basal bone and was separated by fibrous tissues. In conclusion, PCL scaffolds for bone regeneration were biocompatible and advantageous for maintaining space but it needs more studies for predictable bone formation.

Background and Aim

Dental implants are the most common dental treatment to replace missing teeth. However, cases with extensive bone loss are difficult to place the implant due to lack of alveolar bone. To regenerate alveolar bone defects, 3D bone graft materials using CT and 3D printing were developed and it can overcome the weakness of conventional particulate bone grafting materials, because the advantage to maintain the shape more robust during healing time. This study aimed to evaluate a customized 3D PCL scaffold with β -TCP fabricated using a 3D bioprinting system for alveolar bone reconstruction in large animal model.

Methods and Materials

Figure 1. Flow of study

Scaffold characteristics : The PCL scaffolds were manufactured using a 3D bioprinting system. The scaffold pattern was designed with an orthogonal orientation between the layers with a strand-to-strand distance of 400 and 1200 μ m. The strand thickness/strand period was 400/400 and 400/1200.

Figure 2. SEM images of PCL scaffolds (upper 400/400, lower 400/1200) (original magnification: x40)

Animal experiments : The mandibular second and third premolars of 4 adult, male beagle dogs were extracted and a 3 month healing period was allowed. A standardized bone defect, 10.0 $\times$ 5.0 $\times$ 5.0 mm in size was produced on the alveolar ridge using a surgical bur. Each bony defect was filled with sterilized utility wax to maintain the defect form until regenerative therapy. 2 days after surgery, the animals were examined by CT under general anesthesia. After 2 weeks, The 3D scaffolds were fixed surgically with a fixation screw and all defect sites were covered with a resorbable membrane. 8 weeks later, 2 beagles were sacrificed and block sections including the grafted sites were harvested and fixed in 70% ethanol until the microCT scans. **Histology & histomorphometric analysis :** After scanning with micro CT, the sections were fixed with 10% buffered neutral formalin for 2 weeks and decalcified in formic acid followed by a water rinse. The specimens were then decalcified in tissue processor and embedded in paraffin with an embedding center. Serial sections, 3.0 μ m in thickness were cut using a Microtome and each specimen was stained with hematoxylin and eosin (H&E).

Results

In vivo experiment : Micro-CT analysis revealed new bone formation through the grid within the PCL block. the block (400/1200) group had a larger amount of bone formation than the block (400/400) group, there was no significant difference. (p=0.178)

Figure 3. Micro-CT images after the in vivo experiments.

Histologically, both blocks induced bone regeneration around the PCL scaffolds. block (400/1200) group showed a tendency to form bone regeneration around the scaffold as well as into the interior scaffold through penetration. The PCL scaffolds did not directly contact to basal bone and was separated by fibrous tissue. Histomorphometrically, approximately 40% of the defects in all groups were filled with newly formed bone. Block (400/1200) group showed more amounts of bone regeneration than block (400/400) group although there were no significant differences between the groups (p=0.301).

Figure 4. Histology examination of bone regeneration after PCL scaffold implantation. New bone formation was observed above the bottom of the defects (yellow line) in all groups (Block 400/400(a-c), and Block 400/1200 (d-f)). Histomorphometric analysis showed no significant differences between groups although more new bone was observed in Block (400/1200) group.

Conclusions

PCL is easy to manipulate for fabrication of customized scaffolds and it also has excellent mechanical strength. The scaffold design of wide lattice was suitable to allow new bone formation in the bone formation. For general use of PCL scaffold as bone graft materials, strategies for the direct bone contact to PCL is needed in further study.

References

- de Carvalho PS, de Carvalho MC, Ponzoni D. Reconstruction of alveolar bone defect with autogenous bone particles and osseointegrated implants: Histologic analysis and 10 years monitoring. Ann Maxillofac Surg 2015;5:135-139.
- Daga D, Mehrotra D, Mohammad S, Singh G, Natu SM. Tentpole technique for bone regeneration in vertically deficient alveolar ridges: A review. J Oral Biol Craniofac Res 2015;5:92-97.
- Reynolds MA, Aichelmann-Reidy ME, Branch-Mays GL, Gunsolley JC. The efficacy of bone replacement grafts in the treatment of periodontal osseous defects. A systematic review. Ann Periodontol 2003;8:227-265.
- Haggerty CJ, Vogel CT, Fisher GR. Simple bone augmentation for alveolar ridge defects. Oral Maxillofac Surg Clin North Am 2015;27:203-226.