Porcine study on the efficacy of autogenous tooth bone in the maxillary sinus

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Objectives: This study sought to elucidate the effect of autogenous tooth bone material by experimenting on minipig's maxillary sinus and performing histological and histomorphometric analyses.

Materials and Methods: Five 18-24 month-old male minipigs were selected, and right maxillary sinuses were grafted with bone graft material made of their respective autogenous teeth extracted eight weeks earlier. The left sides were grafted with synthetic hydroxyapatite as control groups. All minipigs were sacrificed at 12 weeks after bone graft, which was known to be 1 sigma (σ) period for pigs. Specimens were evaluated histologically under a light microscope after haematoxylin-eosin staining followed by semi-quantitative study via histomorphometric analysis. The ratio of new bone to total area was evaluated using digital software for calculation of area.

Results: All specimens were available, except one on the right side (experimental group), which was missing during specimen preparation. This study demonstrated new bone at the periphery of the existing bone in both groups, showing evidence of bone remodeling, however, encroachment of new bone on the central part of the graft at the 1 σ period was observed only in the autogenous tooth bone group (experimental group). Histomorphometric analysis showed more new bone formation in the experimental group compared to the control group. Although the difference was not statistically significant (P>0.05), the mean percentage area for new bone for the experimental and control groups were 57.19%±11.16% and 34.07%±13.09%, respectively.

Conclusion: The novel bone graft material using autogenous tooth is a good alternative to autogenous bone, comparable to autogenous bone, and outperforming synthetic hydroxyapatite bone graft materials in terms of bone regeneration capacity. Augmentation with autogenous tooth bone materials will reduce donor site morbidity without hampering the safety of the autogenous bone graft.

Key words: Autogenous tooth bone, Miniature pig, Histomorphometric study, Maxillary sinus

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I. Introduction

Bone grafting started to be applied to the pneumatized maxillary sinus in blade implant placement in the late 1970s after grafting in the maxillary sinus was performed by Boyne with the intention of bone augmentation for the first time in 1960. In 1980, Boyne and James\(^1\) published their first paper describing the outcomes in the aforesaid case. With the introduction of root-form implants, the necessity of alveolar bone augmentation has increased; thus, the frequency of maxillary sinus bone graft has started to rise gradually. Afterward, with the advancements in surgical techniques and implant materials, it is one of the most common and successful bone graft options in the maxillofacial area at present. Many clinicians developed a variety of surgical techniques and approaches, and the outcomes of various bone grafting techniques and materials in clinical practice were reported in the 1996 Sinus Consensus Conference\(^2\).

Tricalcium phosphate was the first alternative bone substitute successfully used as maxillary sinus bone graft material\(^3\). After that, lots of bone graft materials such as allogenic grafts, synthetic grafts, and xenogenic grafts have been used.
individually or in combination with autogenous bone in maxillary sinus bone graft. Favorable results of retrospective studies of several bone graft materials were also reported at the 1996 Sinus Consensus Conference. Afterward, with very stable outcomes observed when autogenous bone was employed as maxillary sinus bone graft material in the maxillary molars with at least moderate bone resorption or pneumatization, especially in severely atrophic maxilla, the use of autogenous bone grafts has been recommended. In addition, the unique advantages of autogenous bone as maxillary sinus bone graft material were demonstrated to enable their versatile and useful applications to bone grafting techniques for different defects or lesions.

Recently introduced in South Korea, autogenous tooth bone graft is attracting public attention because it is known to feature enhanced availability of autogenous grafts; thus most likely leading to higher success rates. This graft material was developed as a result of paying attention to the fact that the composition of teeth is almost identical to that of bone, and that tooth-derived material is made of bone components harvested using extracted autogenous teeth. Since it is autogenous, it is immunologically identical to self and without psychological rejection in patients. Furthermore, it is expected to have osteoinduction activity as well as osteoconduction.

In this context, this study intended to clarify any effect of autogenous tooth bone grafts - made by processing extracted teeth that had been discarded in the past - on new bone formation in maxillary sinus bone grafting based on findings of experiments on miniature pigs as lab animals.

II. Materials and Methods

1. Laboratory animals (animal subjects)

Five healthy male miniature pigs weighing approximately 40 kg and with ages of 24 months or so (Prestige World Genetics, Pyeongtaek, Korea) were used as animal subjects. In accordance with the Institutional Animal Care and Use Committee (IACUC) guidelines, every experiment was conducted in the operating room within the laboratory, and all procedures for selection, care, and surgical treatments of animal subjects (lab animals) were implemented after obtaining IACUC’s approval (Medikinetics-IACUC: 100407-001). Any and all surgical procedures and techniques were performed and applied under general anesthesia.

2. Surgical protocol

Atropin (Kwangmyung Pharmaceutical Ind. Co. Ltd., Seoul, Korea) was intravenously administered; xylazine (Rompun; Bayer Korea Co., Seoul, Korea) and ketamin 30 mg (Ketara; Yuhan Co., Seoul, Korea) were intramuscularly injected to induce general anesthesia; endotracheal intubation was then performed using Miller sized-4 laryngoscope and standard straight tube with inner diameter of 5.5 mm and cuff (Portex, Kent, UK); general anesthesia was maintained with 1% euflurane (Gerolan; Choongwae Pharmaceutical Co., Seoul, Korea). To prevent possible infections, epocelin (40 mg/kg body weight; Dong-A Pharm, Seoul, Korea) was intra muscularly administered both preoperatively and postoperatively; to protect the surgical site, soft food was fed to the animals until the completion of wound healing. Miniature pigs were placed in the ventral recumbency position, and then their heads were fixed followed by shaving. After disinfecting the surgical site with betadine, the site was isolated with sterile drapes. For local anesthesia, infiltration anesthesia was performed with lidocaine (2% lidocaine HCl and epinephrine, 1.8 mL; Yuhan Co., Seoul, Korea). Afterward, the left and right mandibular premolars and molars were extracted and delivered to the Korea Tooth Bank (Seoul, Korea) for processing into powdery bone graft material. After about 8 weeks, the maxillary sinus was exposed through the lateral approach, and maxillary sinus floor elevation was carried out using the outfracture osteotomy sinus graft technique. An autogenous tooth bone graft was placed on the right side for the experiment group, and hydroxyapatite (Bone Gros; BioAlpha Inc., Seongnam, Korea), on the left side for the control group. Initially included in experimental group, an animal was excluded from the experimental group because the right maxillary sinus membrane got perforated, indicating failure of maxillary sinus bone grafting. In both experimental group and control group, a bone window was prepared again in the grafted site followed by interrupted suture.

3. Fabrication of autogenous tooth bone materials

The mandibular premolars of the minipigs were extracted on both sides and prepared 8 weeks before the graft procedure. Immediately after extraction, the teeth were trimmed and cleaned of all extraneous material and sterilized in 70% alcohol. The tooth was cut in the cementoenamel junction to divide it into crown and root. Using the crown dentin block, the pulp tissue was totally removed by the retrograde
laboratory without delay to request slide preparation and analysis. The specimens were demineralized with formic acid, and paraffin blocks were made in a routine manner. For each sample, paraffin blocks were cut into 4 μm sections, followed by hematoxylin-eosin staining and histopathological examination under an optical microscope (Olympus BX-51; Olympus Co., Tokyo, Japan). Histomorphometric analyses were performed by observing the respective slides at 100× magnification under an optical microscope. Specifically, after acquiring digital images from a digital camera mounted on the microscope, image analyzing software program (Kappa Image Base-metreo; Opto-Electronics, Gleichen, Germany) was used to determine and analyze the area of newly formed mineralized bone (NB%) in the entire lesion as seen in the acquired images.

5. Statistical analysis

The NB% of each graft material was statistically analyzed using the Mann Whitney U-test at 95% confidence level using the IBM SPSS Statistics (version 19.0; IBM Co., Armonk, NY, USA).

III. Results

1. Gross findings

During this study, miniature pigs remained healthy, and outcomes of the treatment in their grafted sites were good. No major complication such as infection, edema, or exposed bone graft material was observed in any group.

2. Histological findings

Typical histological findings for the experimental group are presented in Figs. 2-4. Fig. 2 shows the experimental specimens under magnification of ×100. Grafted tooth-derived graft materials (asterisks) were evident, showing multiple linear streaks as a dentinal tubular structure. New bone (arrowheads) was growing at the periphery of the tooth-derived materials in Fig. 2. Other specimen under magnification of ×400 showed bone remodeling activity as evidenced by the multinucleated giant cells of osteoclastic activity at the periphery of the graft material with multiple linear streaks (arrowhead in Fig. 3). Another experimental specimen under magnification of ×100 is shown in Fig. 4. Encroaching on the tooth-derived graft material (asterisk),

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**Fig. 1.** Surgical procedure (lateral window approach) with the outfracture osteotomy sinus graft technique. After extraoral skin incision on the infraorbital area, careful dissection was done until we reached the lateral maxillary sinus wall. After bony window opening, the autogenous tooth-derived material was grafted in the floor of the maxillary sinus. The same procedure was done on the left side of the same animal, except the graft material wherein the synthetic hydroxyapatite was grafted. The same procedure was repeated in the remaining 4 experimental animals on the same day. The area of interest was marked(*) on the floor of the maxillary sinus area.

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new bone formation (arrowhead) was identified, showing bone remodeling as evidenced by the incremental lines. In Fig. 5, synthetic hydroxyapatite (asterisk) was partially evident in the histological section of the control group. New bone was also found at the periphery of the grafted hydroxyapatite (arrowheads) but not in the inner portion of the graft space (Fig. 5).

3. Histomorphometric analysis

The area of new bone formation (B), total examined area (T), and ratio of new bone formation (B/T) were presented in Table 1. The area was measured in \( \mu m^2 \) for the area of new bone and total area, and the ratio of new bone formation was calculated in unit %. Although there was no statistical significant difference between the two groups because of the small number of experimental animals (\( P>0.05 \)), the
mean values and standard deviation of the ratio of new bone formation were calculated as 57.19±11.16% for the experimental group and 34.07±13.09% for the control group as summarized in Table 2.

IV. Discussion

Initial immobilization is one of the most critically important factors for the success of dental implantation and is affected mainly by bone quality and bone quantity at the site of implant placement. If it is impossible to improve bone quality, bone quality should be maximized as much as possible, especially in the case wherein there is insufficient bone quantity in the maxillary sinus floor due to sinus pneumatization in the region with low bone strength relative to that of the mandibular and maxillary molars. In this case, maxillary sinus bone grafting to fill with bone graft is essential for the success of implantation.

For maxillary sinus bone graft, autogenous bone has several advantages. In particular, spongy bone contains diverse cells that will contribute significantly to new bone growth after differentiation; autogenous bone graft materials contain bone morphogenic proteins (BMPs) that induce osteogenic cells from the surrounding tissue. Autogenous bone also includes other growth factors involved in the healing and incorporation of the grafted bone. Cortical bone provides osteoconductive scaffolds, and it is substituted with new bone through creeping substitution. Since autogenous bone graft has osteogenesis, osteoconduction, and osteoinduction activities without immune rejection, which leads to rapid healing, autogenous bone grafting is undoubtedly ideal for the reconstruction of defective hard tissue.

Note, however, that it has the disadvantages of limited area or quantity of harvesting, secondary defects caused in the donor site, and relatively high possibility of maxillary sinus repneumatization attributed to the resorption of the graft material over time. Hatano et al. argued that, to avoid possible events of repneumatization for the first two or three years after grafting, non-absorbable or slowly absorbable graft materials should be used. Since defects in the maxillary sinus are a form of "contained-type defects" with their own bony housing, most of the biocompatible bone graft materials can yield satisfactory outcomes. Recently, various graft materials used for maxillary sinus bone grafting have been shown to have no statistically significant difference in the aspects of healing; autogenous bone, allogenic bone, xenogenic bone, and synthetic bone are known to be safe. Therefore, an appropriate material can be selected depending on clinicians’ preferences.

Meanwhile, the use of either xenogenic bone or synthetic bone in combination with a proper volume of autogenous bone in grafting is known to enable healing by osteogenesis and osteoinduction and shorten remarkably the length of time required for healing. In other words, the combination of autogenous bone and bone substitute for grafting may be characterized by increased resistance to the resorption of graft material; hence the ability to maintain a sustainable volume of the material at the defective site. Since autogenous tooth bone graft materials are of self-origin, the positive effects of osteoconduction as well as osteoinduction can be expected.

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Table 1. Histomorphometric analysis of the new bone 12 weeks after the sinus bone graft

| Experimental animal | New bone (B) (μm²) | Total (T) (μm²) | New bone-total area ratio (B/T) (%) |
|---------------------|--------------------|----------------|-----------------------------------|
| Pig 1               |                    |                |                                   |
| Left                | 351,929            | 1,005,801      | 47.93                             |
| Right*              |                    |                |                                   |
| Pig 2               | 42,394             | 243,498        | 17.41                             |
| Right               | 127,553            | 244,264        | 52.21                             |
| Pig 3               | 69,121             | 242,606        | 28.49                             |
| Right               | 577,121            | 1,006,689      | 57.32                             |
| Pig 4               | 79,915             | 243,583        | 32.80                             |
| Right               | 113,414            | 243,199        | 46.63                             |
| Pig 5               | 115,443            | 241,842        | 47.73                             |
| Right               | 175,314            | 241,460        | 72.60                             |

Right sinuses of all experimental pigs were filled with autogenous tooth bone, whereas left sinuses were filled with synthetic hydroxyapatite as control groups. New bone area (B) and total area (T) was estimated and the ratio of new bone area over total area (B/T) was calculated for each specimen.

*Specimen from the right maxillary sinus (experimental group) of the pig 1 was missing during specimen preparation and was designated as negative in this table.

Table 2. The ratio of new bone over total bone for 4 experimental and 5 control specimens

| Experimental animal | New bone/total area ratio (%) |
|---------------------|------------------------------|
|                     | Right (experimental) | Left (control) |
| Pig 1               | -.             | 47.93          |
| Pig 2               | 52.21           | 17.41          |
| Pig 3               | 57.32           | 28.49          |
| Pig 4               | 46.63           | 32.80          |
| Pig 5               | 72.60           | 47.73          |
| Mean (standard deviation) | 57.19 (11.16) | 34.87 (13.09) |

*Specimen from the right maxillary sinus (experimental group) of the pig 1 was missing during specimen preparation and was designated as negative in this table.
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