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Effect of bioactive glass granules and polytetrafluoroethylene membrane on repair of cortical bone defect

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The effect of bioactive glass (BG) granules and nonresorbable polytetrafluoroethylene (PTFE) membrane on the repair of cortical bone defects was studied. Monocortical holes (diameter 3.0 mm) were drilled in rabbit tibia. Sixteen holes were filled with BG granules (diameter 630–800 μm). Twelve holes were left empty and covered with PTFE membrane. No material was used at ten control holes. All experiment areas were covered with periosteum attached to the soft tissue flap. Histomorphometric evaluation of resection specimens showed that new bone and glass particles formed a continuous bridge in the BG group at the upper part of the hole, occupying 73.6% and 61.7% of the defect at 6 and 12 weeks, respectively. If only the amount of bone but not glass particles was included in the measurements the corresponding figures were 31.4% and 41.5%. The bone repair in the PTFE group was 12.1% and 11.3% and in the control group 25.1% and 23.3% at 6 and 12 weeks, respectively. The results indicate that BG granules improve repair of cortical bone defects and PTFE membrane seems to impair bone formation in these defects.

1. Introduction

An insufficient amount of bone, due to anatomical reasons or as a consequence of trauma, infection, resorption, neoplasia and other pathological processes, limits the use of dental implants for oral rehabilitation. Several surgical techniques have been used in attempts to preserve or rebuild the edentulous alveolar ridge with autologous bone or various bone substitutes [1, 2]. The advantage of using bone substitutes is the avoidance of bone grafting procedures. Also, sometimes there is not enough bone available for grafting. Several studies suggest that bioactive glass is a promising bone substitute material [3, 4].

The principle of guided tissue regeneration (GTR) is one method commonly used to achieve bone at small defects. This technique, which utilizes a membrane over the bone defect area, was originally developed for treatment of bone loss due to periodontal disease [5]. The aim of this study was to compare the effect of BG granules and PTFE membrane on the repair of cortical bone defects in rabbit tibia.

2. Material and methods

Ten adult New Zealand rabbits of both sexes (weight 3.5–4.5 kg) were operated on under general anesthesia and standard aseptic conditions. The animals were given an intramuscular injection of ketamine hydrochloride (Ketalar 50 mg/ml, Parke-Davis, Barcelona, Spain) 0.6 ml/kg, medetomidine (Domitor 1.0 mg/ml, Lääkefarmos Oy, Turku, Finland) 0.1 mg/kg and xylazinum (Rompun 20 mg/ml, Bayer, Leverkusen, Germany) 0.5 mg/kg. Procaine benzylpenicillin 50 000 IU/kg (Procapen 300 000 IU/ml, Orion, Espoo, Finland) was given to the animals preoperatively. The skin at the operation area was shaved and cleaned with antiseptic polyvidone iodine solution (Betadine 100 mg/ml, Leiras, Tammisaari, Finland). Lidocaine (Xylocain adrenalin 5 mg/ml, Astra AB, Södertälje, Sweden) was used for local anaesthesia.

After elevating the musculoperiosteal flap two monocortical holes (diameter 3.0 mm) were made in medial aspect of metaphyseal area using a conical drill (Frialit 3-0, Friedrichsfeld GmbH, Mannheim, Germany) under continuous sterile saline irrigation. Sixteen holes were filled with BG granules (diameter 630–800 μm) (Fig. 1a). The composition of BG used was: SiO_2 53.0, Na_2O 23.0, CaO 20.0, and P_2O_5 4 (wt %). Twelve holes were left empty and covered with PTFE membrane (Gore-Tex®, W. L. Gore and Assoc., Inc. Flagstaff, Az, USA) (Fig. 1b). No material was used at ten control holes (Fig. 1c). The experiment area of each study group was covered with periosteum attached to the soft tissue flap. Animals were killed after 6 and 12 weeks with an overdose of ketamine hydrochloride and carbon dioxide.

Resection specimens were fixed in 4% neutral formalin and embedded in plastic (Technovit 7200, Kulzer GmbH, Wehrheim, Germany). The blocks were cut in two parts longitudinally through the midplane of the hole. Histological sections for light microscopy were prepared using a cutting–grinding

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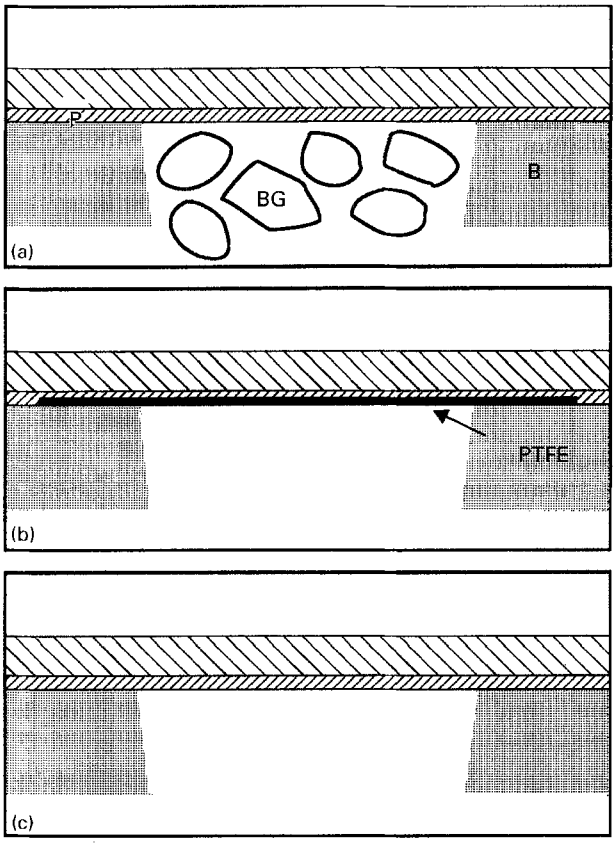

Figure 1 Experimental design. (a) Cortical defect filled with granules of bioactive glass (BG). (b) Defect covered with polytetrafluoroethylene (PTFE) membrane. (c) Control defect. P = periosteum, B = bone.

method (Exakt-Apparetebau, Hamburg, Germany) [6] and stained with toluidine blue. The other half of the block was used for scanning electron microscopy (SEM). SEM pictures were used for evaluation of bone repair. Repair was assessed as percentages of the total defect area using a computerized analysis system (Micro-Scale TC, Digithust Ltd, Royston, UK).

3. Results

Six specimens were excluded from the analysis due to failure at surgery or in the laboratory. Histological evaluation revealed mild mononuclear inflammatory reaction in most specimens of the BG group but only in a few PTFE and control specimens. Multinuclear giant cells of foreign body reaction were not observed in any specimens.

Results of histomorphometrical analysis on bone repair are presented in Table I. If the area occupied by the granules in the BG group is not taken in account, 55.1% (±14.2) and 53.4% (±28.2) of the remaining defect area was covered by bone at 6 and 12 weeks, respectively. Newly formed bone and BG granules formed a continuous bridge through the outer opening of the defect area in 10/15 specimens (66.7%) of the BG group (Fig. 2a). The vast majority of the BG granules were completely surrounded by bone and there was close contact between bone and granules. In the PTFE group, a thin bone bridge was seen immediately beneath the membrane without any interposing soft tissue (Fig. 2b). The closure of the defect was incomplete in all but one specimen. A continuous bone bridge was observed in 6/8 specimens (75.0%) of the control group (Fig. 2c).

TABLE I Repair of cortical bone defect using bioactive glass granules (BG) and polytetrafluoroethylene (PTFE) membrane, given in percentages of the total defect area

BG	PTFE	Control	
6 Weeks			
No. of specimens	9	5	4
Bone	31.4 (±9.4)	12.1 (± 8.6)	25.1 (±10.0)
Bone and BG	73.6 (±10.7)		
12 Weeks			
No. of specimens	7	4	3
Bone	41.5 (±18.7)	11.3 (±4.0)	23.3 (±18.8)
Bone and BG	61.7 (±32.1)		

Difference in bone formation between BG and PTFE groups is statistically significant (6 weeks $p = 0.007$; 12 weeks $p = 0.034$, Tukey's test).

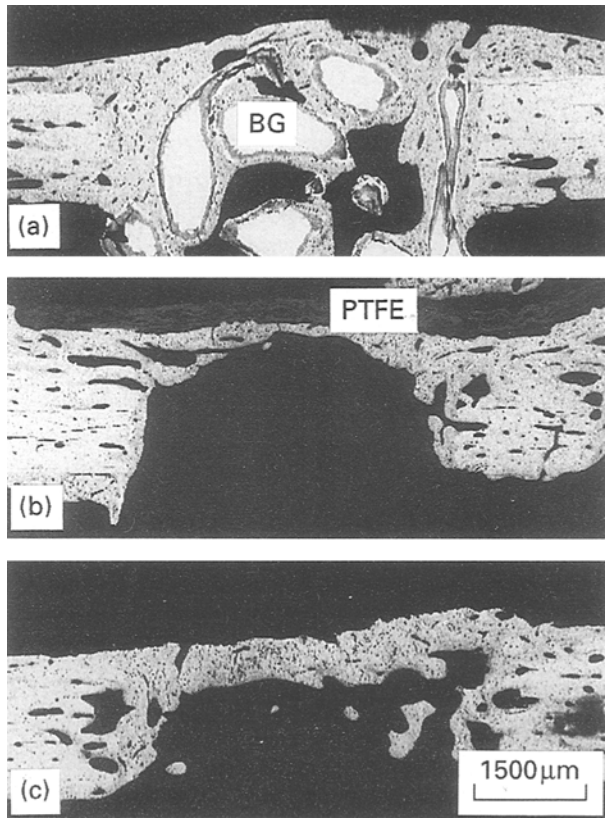

Figure 2 (a) SEM picture showing complete closure of the defect area filled with BG granules at 6 weeks. Note tight contact between bone and BG granules. (b) Newly formed bone forms a thin bridge over the defect area covered with PTFE membrane at 6 weeks. (c) New bone formation in control defect at 6 weeks.

4. Discussion

Repair of bone defects using various kinds of bone substitutes has been investigated in order to avoid a second procedure to harvest autogenous bone graft [2, 7]. A substitute material promoting new bone

formation is useful, for example, in oral implantology where a sufficient amount of bone is mandatory to support fixtures. The present study was designed to evaluate the repair of cortical bone defects using two materials with different biological properties. Bioactive glass (BG) is a bone-conducting material, while polytetrafluoroethylene (PTFE) membrane is an inert material.

BG has been shown to be a promising bone substitute material in experimental bone defects [4, 8]. BGs, first introduced by Hench *et al.* in 1971 [9], are silicate glasses containing sodium, calcium and phosphate as the main components. BG used in this study has been shown to bond chemically to bone [8, 10, 11]. Bone bonding of BG is based on the formation of a calcium phosphate surface layer on the glass when exposed to body fluid [12].

Nonresorbable PTFE membrane is clinically in common use in connection with guided tissue regeneration (GTR) [13]. The objective of the membrane is to facilitate bone repair by preventing the growth of soft tissues into the defect area. However, variable results concerning the bone regeneration achieved using this membrane have been published [14, 15]. Perforation of oral mucosa may be associated with the use of PTFE membrane. Furthermore, a secondary procedure is needed to remove the membrane at a later stage.

Clearly, better bone repair was obtained in the BG group than in the PTFE and control groups. New bone grew along BG particles and formed a continuous bridge over most defects in the BG group. The vast majority of the BG granules between the edges of cortical bone were completely covered by new bone. BG granules and the formed bone together occupied over 60% of the defect area. Chemical bonding of BG granules to the formed bone makes the bridge tight and strong. Push-out tests using conical BG implants with a smooth surface have shown that fracturing does not take place at the interface between the implant and bone, but within the surrounding cortical bone [16]; however, the biomechanical strength of bone–BG composite formed in cortical defects remains to be studied.

In the PTFE group, only a thin bone bridge formed under the periosteum. This finding is in accordance with the observations made by Aaboe *et al.* [17]. They also found that a thin layer of new bone connected the edges of cortical bone defects covered with PTFE. Complete closure of the defects was constantly seen in their study. In contrast, we found that closure of defects was incomplete. The amount of bone formed in the PTFE group was significantly less than in the control group.

The highest amount of new bone formation in the cortical defects covered with intact periosteum was achieved in the BG group. Because of the bone-conducting property of BG, more bone was found in this group than in the control holes. Whether similar results can be obtained in situations where the periosteum is defective remains to be investigated.

The present results indicate that BG granules improve bone repair, while a PTFE membrane seems to impair bone formation in cortical defects. Consequently, the usefulness of BG granules in various clinical applications needs to be studied. For example, PTFE membrane has been used in the connection of fixtures inserted in alveolar sockets immediately after tooth extraction [14, 18, 19]. Good bone repair achieved with BG granules together with the bone-bonding ability encourages continued experiments in this direction.

References

1. D. JENNINGS, *J. Prosthet. Dent.* **61** (1989) 575.
2. L. HENCH and J. WILSON, *MRS Bull.* **16** (1991) 62.
3. L. HENCH, H. STANLEY, A. CLARK, M. HALL and J. WILSON, in "Bioceramics", edited by W. Bonfield (Butterworth-Heinemann, Oxford, 1991) p. 231.
4. J. HEIKKILÄ, A. AHO, A. YLI-URPO, Ö. ANDERSSON and R.-P. HAPPONEN, *Acta Orthop. Scand.* **6** (1993) 678.
5. S. NYMAN, J. LINDHE and T. KARRING, in "Textbook of clinical periodontology", edited by J. Lindhe (Munksgaard, Copenhagen, 1989) p. 450.
6. K. DONATH and G. BREUNER, *J. Oral Pathol.* **11** (1982) 318.
7. P. BOYNE, *Curr. Opin. Dent.* **1** (1991) 277.
8. J. HEIKKILÄ, A. AHO, A. YLI-URPO and R.-P. HAPPONEN, submitted.
9. L. HENCH, R. SPLINTER, W. ALLEN and T. GREENLEE JR., *J. Biomed. Mater. Res.* **2** (1971) 117.
10. G. ITO, T. MATSUDA, N. INOUE and T. KAMEGAI, *ibid.* **21** (1987) 485.
11. Ö. ANDERSSON, G. LIU, K. KARLSSON, L. NIEMI, J. MIETTINEN and J. JUHANOJA, *J. Mater. Sci.* **1** (1990) 219.
12. L. HENCH and H. PASCHALL, *J. Biomed. Mater. Res.* **5** (1974) 49.
13. R. CAFFESSE and C. QUINONES, *Compend. Contin. Educ. Dent.* **8** (1992) 166.
14. R. LAZZARA, *Int. J. Periodontics Restorative Dent.* **5** (1989) 333.
15. K. WARRER, K. GOTFREDSEN, E. HJÖRTING-HANSEN and T. KARRING, *Clin. Oral Implants Res.* **2** (1991) 166.
16. Ö. ANDERSSON, K. KARLSSON, K. KANGASNIEMI, *J. Non-Cryst. Solids* **119** (1990) 290.
17. M. AABOE, E. M. PINHOLT, E. HJÖRTING-HANSEN, E. SOLHEIM and F. PRAETORIUS, *Clin. Oral Implants Res.* **4** (1993) 172.
18. S. NYMAN, L. LANG, D. BUSER and U. BRÄGGER, *Int. J. Oral Maxillofac. Implants* **5** (1990) 9.
19. W. BECKER and B. BECKER, *Int. J. Periodontics Restorative Dent.* **10** (1990) 377.

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