EVALUATION OF OSTEOSYNTHESIS AND BIODEGRADATION IN CaO-SiO₂-P₂O₅-B₂O₃ GLASS-CERAMICS

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Introduction:

AW-glass ceramics (Cerabone®) have been used as a bone graft substitute because of their excellent mechanical properties and osteoconductivity. However, the biodegradability of Cerabone® is so poor that it remains in the living body for a long time. The present authors found that some kind of glass-ceramics in the CaO-SiO₂-B₂O₃ (CS10B) system is bioactive and biodegradable in vitro. Moreover, the CS10B implant had a significantly higher resorption rate than HA and TCP, the tensile strength of CS10B was found to be much greater than that of TCP in vitro. We postulated that if we found an ideal composition between Cerabone® and CS10B, that glass-ceramics would be more osteosynthetic than CS10B, and more biodegradable than Cerabone®.

In this study, we compared the biodegradation and osteoconduction properties between Cerabone® and two kinds of CaO-SiO₂-P₂O₅-B₂O₃ glass-ceramics, which were thought to be more improved composition than CaO-SiO₂-B₂O₃ (CS10B) system.

Methods:

The compositions of examined glass-ceramics are listed in Table 1. Ca₄O₅, SiO₂, B₂O₃, MgO, Ca₃ (High Purity Chemicals, 99.99% in CaCO₃, 99.9% in SiO₂, 99.9% in others), and Ca₃P₂O₇ (Aldrich, 99.9%) were used as the starting materials. The pre-mixed batches were placed in a platinum crucible and melted at 1450°C for 2hrs. The melts were poured into a stainless steel mold and allowed to cool. The resultant glasses were pulverized into 3-4 μm particles using a zirconia planetary pot mill for 5hrs with zirconia balls. With these powders, porous glass-ceramics were prepared by polymeric sponge method. The sintering temperature is 1000°C for AW-glass ceramics, 800°C for the others. Pore sizes ranged 300 to 500 μm and the porosity ranged 70-75%. And the porous bodies were cut into 3-5mm cube form before implantation.

<table>
<thead>
<tr>
<th>Sample</th>
<th>CaO</th>
<th>SiO₂</th>
<th>P₂O₅</th>
<th>B₂O₃</th>
<th>MgO</th>
<th>Ca₂F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerabone®</td>
<td>44.7</td>
<td>34.2</td>
<td>16.3</td>
<td>4.6</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>CSPB2</td>
<td>40.07</td>
<td>40.28</td>
<td>8.1</td>
<td>5.0</td>
<td>2.3</td>
<td>0.25</td>
</tr>
<tr>
<td>CSPB3</td>
<td>43.76</td>
<td>43.41</td>
<td>4.05</td>
<td>7.5</td>
<td>1.15</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Table 1. Compositions of three different kinds of glass-ceramics (wt.%).

A single level posterolateral fusion was performed on thirty-nine New Zealand white male rabbits. The study was approved by the Standing Committee on Ethics at the Laboratory for Animal Research at the Clinical Research Institute, SNUH. The animals were divided into three groups by implants materials: CSPB2, CSPB3 and Cerabone®. We exposed the bilateral transverse processes of the 5th and 6th lumbar vertebrae, implanted 3cc volume graft on each side. Routine posteroanterior radiographs of the lumbar spine were taken immediately after surgery to ensure proper surgical placement and to determine the initial area occupied by the ceramic implants. Additional plain radiographs were obtained every 2 weeks after surgery. All animals were euthanized 12 weeks after surgery and the 5th and 6th vertebrae, including the transverse processes and the bilateral fusion masses, were harvested. The fusion rates were studied by radiographic review and manual palpation. The area occupied by the ceramics by final radiograph was divided by the area occupied by the ceramics by the initial radiograph using Image-Pro® plus (Media Cybernetics, USA). Uniaxial tensile strength was measured on 7 cases in each group by Instron electromechanical materials testing. Undecalcified sections were stained with H & E methods.

Results:

We analyzed 11 rabbits of CSPB2 group, 11 rabbits of CSPB3 group, and 10 rabbits of Cerabone® group because of infection and death of animals. Solid fusion was detected 9 of 11 (81.8%) in the CSPB2 group, 10 of 11 (90.9%) in the CSPB3 group, and 8 of 10 (80.5%) in the Cerabone® group by manual palpation. On radiographs, radio-opacities of three kinds of ceramics were practically unchanged from immediately after surgery until 12 weeks after surgery. But homogenous shadows were observed in three kinds of ceramics, which represented fusion mass formation by bone ingrowth (Fig.1).

The proportions of the area occupied by ceramics at the final radiographs to the area occupied by ceramics at the initial radiographs were 90.8%±14.0 in Cerabone®. 73.1%±11.5 in CSPB2 and 73.5%±10.5 in CSPB3. The percent areas of the CSPB2 and CSPB3 groups in the final radiographs were significantly smaller than those of Cerabone® (p<0.001), by Kruskal-Wallis test. The mean values of the tensile strengths of the implants were 214±57.3 N in Cerabone®, 217±66.1 N in CSPB2 and 217±70.1 N in CSPB3. The mean values of the tensile strengths were not significantly different among the three kinds of ceramics.

Histologic appearances of the fusion masses among the groups were consistent with the radiologic findings and all of the three kinds of glass-ceramics showed excellent results. Bone tissue has been formed inside pores and along pore walls of the porous ceramics, tight contact with the bone without any inflammatory reaction or fibrous encapsulation. Remodeling processes were also found in three groups. But, the margins of pores in CSPB3 were slightly more smoothened than those of Cerabone®, which reflected the biodegradability of CSPB3 (Fig.2).

Discussion:

CSPB2 and CSPB3 had similar tensile strengths and fusion rates of the fusion masses of Cerabone®, however it degraded more rapidly than Cerabone®. Moreover, CSPB2 and CSPB3 showed more improved results in osteoconductivity than our previous study of CS10B. The advantages of a resorbing material are obvious. By implanting biodegradable ceramics, a completely biological and physiologic situation of bone healing can be achieved. So, these results suggest that the osteoconductive, biodegradable glass-ceramics of CaO-SiO₂-P₂O₅-B₂O₃ system can be used as an alternative new bone graft substitute to Cerabone®.

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