POROUS CARBON-CARBON COMPOSITE AS AN ARTIFICIAL BONE TESTED *IN VIVO*

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Introduction

The potential of carbon materials as artificial organs has been recognized since the early 1970s. In first experiments with animals, knee ligaments were removed and successfully replaced by carbon fibers.[1] Experiments on sheep and rabbits[2] demonstrated some unique features of carbon-carbon composite compatibility with skin. Carbon materials retain bacteriostasis that is of a great significance in preventing a traumatized surface from becoming infected.[3, 4] The biocompatibility of carbon surfaces with blood, muscles and bone tissue, combined with the adjustable chemical and mechanical properties of carbon materials, makes them suitable for all kinds of medical implants in living tissue. Hart valves, joints, ligaments and dental implants have been tested in animals and examined clinically.

The successful application of implants requires the suitable diagnostic, especially x-ray and MR imaging, in postoperative period. Therefore, implants should not only fulfill biomedical demands but also allow imaging of all structures with minimal artifacts. It appears that artifacts produced by carbon material are fivefold lover compared to commercially available implants.

A goal of current implantology research is design of devices that induce controlled and rapid healing. Bone implants should contain interfacial matrix with a composition and structure characteristic of bone and the matrix should have adequate biomechanical properties.[5, 6] Carbon-carbon (C-C) composite, with controlled porosity and adjusted mechanical properties, was expected to meet these goals and provide stable fixation between bone and implant. [7] That was the reason to investigate the possibility of producing C-C composite artificial skull bone.

C-C composite used for implantation

The C-C composite was prepared out of short carbon fibers (>10 mm), randomly oriented and mixed with fenol-formaldehide resin. After polymerization of the resin, composite was carbonized in the nitrogen atmosphere up to 1000^o C with heating rate 10 ^{0}C/h. Porosity of the composite was controlled by volume fraction of the resin and the amount of applied pressure during polymerization.[7] The specimen with 40% of open porosity and 80 MPa flexural strength was chosen for implantation. Electron microgrph of the composite fracture is presented in Figure 1.

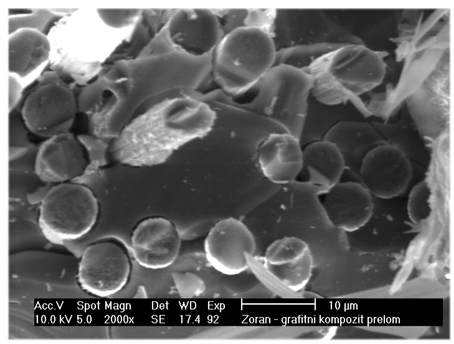


Figure 1. Electron microgrph of the composite used for implantation

Porous C-C composites were used to produce implants shaped as a disks, 2 cm in diameter and 2.5 mm thick, used for implantation. The implants were made to match the size of the artificial defects induced in the parietal bone. The peace of the original bone removed from dog's scull and the C-C implant are presented in Figure 2.

Figure 2. Original bone and C-C implant

Operation

A group of nine dogs was used in order to test biocompatibility of C-C composite. During the operation a part of a skull bone was removed and replaced with CFRC disk. The fixation of the disk was achieved by interjection into the laminate of the parietal bone. That phase of operation is shown in Figure 3. The position of the implant is visible in the radiograph of the dog's head taken immediately after operation, presented in Figure 4.

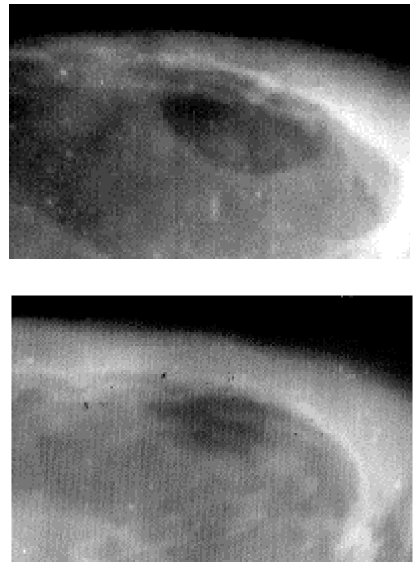
Figure 3. Implantation of the C-C disk

Figure 4. Radiograph of the dog's head taken immediately after operation

Results

The animals were under permanent observation for 5 mounts after the operation. Inflammation of the wounds was not observed on any of nine dogs probably partially due to the bacteriostasis effect of the carbon materials. Blood tests were made daily and the radiographs of the skull were taken weekly. The behavior of the dogs was normal indicating no brain damage or disturbance of any kind.

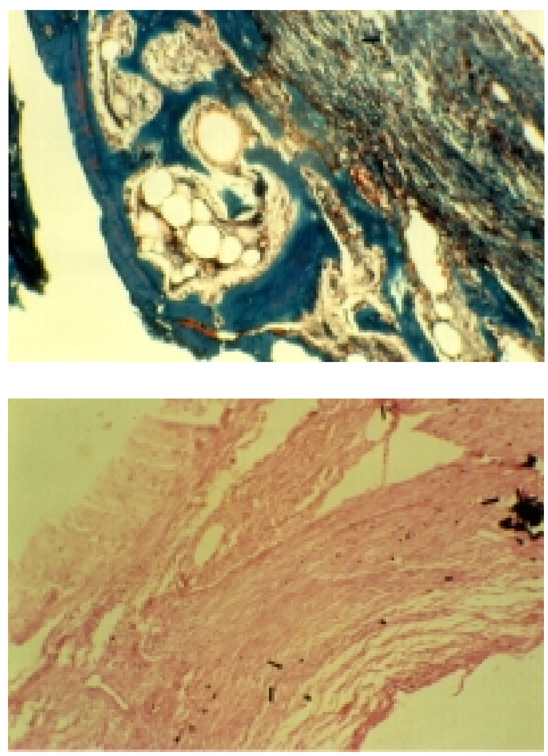
The implanted C-C disks were visible in the radiographs as shaded area 1.7 cm in diameter (Fig. 4). In the firs three mounts the size of the defect remained unchanged, after four mounts the diameter of the defect was 3 mm shorter and after five mounts reduced to 1.2 cm. The healing progress is presented in Figure 5, where the reduced size of the defect area is evident. The radiographs were taken instantly after operation and five mounts later.



(a)

(b)

Figure 5. The radiograph of the implant after operation (a) and five mounts later (b)



(a)

(b)

Figure 6. Photomicrographs of the bone-implant interface recorded after three (a) and five (b) mounts.

Four out of nine dogs were sacrificed during the experiment in order to carry out histological studies at the bone-implant interface. Photomicrographs recorded after three and five mounts are presented in Figure 6. It was clearly observed that a new bone was generated in the open pores of the implant. Significant increases of bone tissue formation in the defect occurred. C-C composite implant integrated well with bone tissue in the healing process of parietal defect. The bone was united completely with the edge of the implant after five mounts.

Conclusion

Porous C-C composite is suitable material for bone replacement. The implant integrates with the newly developed tissue and stimulates the new bone tissue growth.. The inflammation of the wounds was not observed and the results of the blood tests were regular. Although, implant was placed close to the brain membrane, the behavior of dogs was normal during the healing period of five mounts.

References

[1] E. Fitzer, Angew. Chem. Int. Ed. Engl., **19** (1980) 375-385

[2] G. M. Jenkins and C. J. Grigson, J. Biomed. Mat. Res., **13** (1979) 371-394

[3] Z.K. Kabovich, Soviet Union Patent 1694124, 1991.

[4] W. Shen,S. Wen, N. Cao, L. Yheng, W. Yhou, Z. Liu and J. Gu, Carbon, **37** (1999) 356-358.

[5] D.A. Puleo and A. Nanci, Biomaterials, **20** (1999) 2311-2321.

[6] P. Ducheyne and Q. Qiu, Biomaterials, **20** (1999) 2287-2303

[7] Z. Laušević, B. Prokić and M. Laušević, Hem. Ind. (in Serbian), **47** (1993) 179-183.