Bioactive Surface Treatment of Carbon-Fiber Reinforced Composite Hip Stem in an Ovine Model

Introduction:
Using carbon-fiber reinforced composite (CFRP) as materials of hip joint prostheses possess theoretical advantages over metal materials, such as more lucid interpretation at the periosteospongy interface with imaging modalities by its radiolucent nature, an allergy-free property without metal ion, and less prothetic breakage by its fatigue resistance. Moreover, because it is easy to design the modulus of elasticity to match the surrounding bony structure, a CFRP stem can potentially minimize the stress shielding/bone resorption commonly associated with stems made from traditional metals [1,2]. Furthermore, it can easily pass through a security gate with a metal detector. Despite these perceived benefits, CFRP stems are not yet in a practical stage for clinical use because the optimization of both stem design and surface finish for bone ongrowth has not achieved [3,4].

This study examined radiological and histological results of an uncemented CFRP stem with a novel surface modification using titania (TiO2) and hydroxyapatite (HA) in an adult ovine model after 6 and 12 months.

Materials and Methods:
Fourteen skeletally mature ovines (18 months old) were used in this study. Unilateral hemi-arthroplasty of the hip was performed through a anterolateral approach under general anesthesia using an uncemented CFRP femoral stem or a titanium alloy (Ti6Al4V) stem as a control (Fig. 1). An alumina ceramic modular femoral head was used.

Stems with two sizes were designed based on CT data obtained from 6 ovines sacrificed for other experiments. Both the CFRP and titanium stems were in the same geometry with a straight tapered structure for proximal fixation. CFRP stems were manufactured from carbon fiber reinforced polyetheretherketone (PEEK). On the surface of the CFRP stems, protuberances with 0.1 mm height and an interval of 1 mm were molded for scratch fixation against the femoral canal. After coating with a titania layer, the surface of the stems was coated with HA in about 17 mm thickness by a deposition technique. On the other hand, the titanium stems were coated with commercially pure Ti, using a plasma-spray process, and then coated with HA onto the plasma-sprayed surface also using a plasma-spray technique.

Fixation of implants was evaluated at 6 months (CFRP, n=2; Ti; n=5) and 12 months (CFRP, n=2) after excluding ovines with early complications indicated by severe limping (CFRP, n=2; Ti; n=1) or ovines for early evaluation of the implants (CFRP, n=2) at 4 weeks. Bilateral femora from each animal were harvested, radiographed and CT-imaged (0.5mm of pitch). The specimens were embedded with polymethylmethacrylate and were sectioned perpendicular to the long axis of the stem at 5 locations (10, 30, 50, 70 and 90mm from the femoral neck cut level). Cut sections were radiographed and a 100μm slab from each section block was obtained for histology. Stievend"s Blue stain was used and the histology was evaluated under a light microscope.

Results:
In the CFRP group, two cases achieved bony fixation between the femur and the stem radiologically and histologically (Fig. 2). However, the remaining two showed fibrous fixation between the femur and the stem (Fig. 3). In the titanium stem group, bony fixation between femur and the stem was observed in all the 5 cases radiologically and histologically.

Discussion:
Although PEEK has excellent biocompatibility suitable for orthopaedic implants [5], a clinical high rate of aseptic loosening with a CFRP stem [4] suggests that further improvements in the initial stability and bioactive surface finish to accelerate bone ongrowth are necessary in a load bearing condition. In this study, bone-ongrowth stable fixation of the CFRP stem with the titania and HA coating was achieved in the half of the cases without fractures or subsidence. Compared with Ti stems, however, the rate of bone-ongrowth in the CFRP stem was lower. In the CFRP cases with fibrous fixation, stem subsidence occurred. Further improvement in surface geometry to enhance the initial stability is needed for a higher success rate, however, this study demonstrated that bone-ongrowth fixation of uncemented CFRP stem can be achieved with bioactive surface treatment of the composite under a load bearing condition.

References:

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