In vivo evaluation of bioactive-glass-ceramics coating and hydroxyapatite nano-coating on steinman pin: a quantitative biomechanical and histomorphometric study in rabbit

ABSTRACT INTRODUCTION:
Steinman-pins have widely been used for stabilization between bones for fracture and other cases in orthopedics field. Many research reported that, in particular, a surface coating using hydroxyapatite (HA) improves bone bonding strength of implant not only for S-pin but also for various screws. Moreover, a variety of ceramics coating techniques is frequently used. Especially, the bioactive glass-ceramics coating has been reviewed positively. Amongst many bioactive glass-ceramics, CaO-SiO2-P2O5-B2O3 glass-ceramics are known for high bioactivity and osteoconductivity, and also high osseointegration for cases of metal implant with surface coating compared to those without coating. BGS-7 is a composition with high mechanical strength and low absorption rate among CaO-SiO2-P2O5-B2O3 glass-ceramics. The purpose of this study is to evaluate how S-pins with BGS-7 coating affect bone bonding by stages of insertion in comparison with Cerabone-AW and hydroxyapatite nano coating as the result of author’s past test on CaO-SiO2-P2O5-B2O3 glass-ceramics and to conclude whether BGS-7 is suitable as a coating material.

METHODS:
Coating Processes and Implant Characteristics
Steinman-pin (Solcoibiomedical, Seoul) is made of stainless steel with 2.2 mm diameter. Using enamelling method, a test was performed inserting three S-pins on each ilium; 2.2mm Steinmann pin (S-pin) with a coating of BGS-7 (30um), Cerabone-AW (30µm, Cerabon), HA (100nm, HA1), two times of coatings of HA (300nm, HA2) as opposed to S-pin without coating. The composition of CaO-SiO2-P2O5-B2O3 based glass-ceramic, named BGS-7, was CaO 41.8, SiO2 35.8, P2O5 13.9, B2O3 5.0, CaF2 2.0, MgO 6.0 wt%. The material to make Cerabone® AW is SiO2, CaCO3, CaHPO4, ZnH2O, HPO3, Mg, CaF2; with more than 99.9% purity batching 200g of CaO 44.9 wt%, SiO2 34.2 wt%, P2O5 16.3 wt%, MgO 4.6 wt%, CaF2 0.5 wt% composition.

Surgical Model
Fifty five adult New-Zealand white male rabbits of average weight (3.2 ±3) kg were used in this study. This study was approved by the Standing Ethical Committee at the Laboratory for Animal Research at the Clinical Research Institute of our hospital. Surgical procedures were performed to iliums on both sides under general anesthesia. Stepwise preparation of the implant bed was performed by drilling using 2mm drill bit. Four different implant types (BGS-7, HA1, HA2 and Cerabone-AW) were inserted into each rabbit (3 different implants were inserted on each side of each ilium). Animals were subdivided into three groups (15, 20 and 20 animals in the 2, 4, and 8 week groups) according to time of sacrifice.

Tensile testing
Half of the animals per group (2, 4 and 8 week groups) were used for tensile testing and the others were used for histologic evaluations. Tensile testing was performed using an Instron testing machine fitted with a calibrated load-cell of 10 N.

Histomorphometric analysis
Non-decalcified ground sections were prepared and H&E stained. One central section was prepared from each implant using a cutting unit. Sections were ground along the axial implant axis. Histomorphometric evaluations of bilateral coronal implant halves were carried out. The axial halves of implant contours were used to compare implant types. The percentage lengths of direct bone-to-implant contacts with respect to total implant surfaces were measured in the regions of interest.

RESULTS SECTION:
Mean surface roughnesses (Ra) of the four materials were not significantly different (p<0.05).

Tensile test analyses
The mean tensile strength of BGS-7 implants was significantly greater than that of S-pin (p=0.0207 and p=0.0032 and p=0.0014, respectively) and HA1 (p=0.0242, p=0.0001 and p=0.001, respectively) at 2, 4 and 8 weeks and the HA2 at 4 and 8 weeks (p=0.0054 and p=0.0014, respectively). The mean tensile strength of Cerabone-AW was also significantly higher than S-pin (p=0.039 and 0.0016, respectively) and HA1 (p=0.0018 and p=0.0012, respectively) at 4 and 8 weeks and the HA2 (p=0.0017) at 8 weeks. The mean tensile strengths of S-pin and BGS-7 at 4 and 8 weeks were higher than that of 2 weeks. The mean tensile strength of Cerabone-AW increased progressively according to the periods of breeding.

Histologies
At week 2 postoperatively, S-pin and HA1 implant sections showed a definite clear line at the bone/implant interfaces. In contrast, the BGS-7 and Cerabone-AW implant sections showed direct contact, and they had higher contact ratios than S-pin and HA1. At the stage of 4th week after a surgery, BGS-7 and Cerabone-AW showed high osseointegration rate with bones whereas S-pin resulted in low osseointegration rate. Especially for HA1, the connected part with bones was separated again. Meanwhile, HA2 showed higher direct bone osseointegration rate than HA1. At the stage of 8 weeks, S-pin had lower bone osseointegration rate similar to 4th week result while the osseointegration rate for HA1 has slightly been improved. BGS-7 or Cerabone-AW showed higher bone osseointegration rate than S-pin or HA1. HA2 had no difference with 4th week, showing direct bone osseointegration partly but lower osseointegration rate than BGS-7.

DISCUSSION:
BGS-7 pin shows higher osseointegration as twice as S-pin by stages in tensile test analysis and so does Cerabone-AW. This means that it might give useful result from clinical standpoint because BGS-7 or Cerabone-AW when coated in S-pin results in more increased osseointegration than S-pin from 2nd week and it gets higher by time. Hydroxyapatite nano-coating in this study couldn’t provide the increase of osseointegration. Besides, HA1 showed lower osseointegration strength from the 4th week tensile test, which concludes that coating affects negatively on osseointegration. For HA2, there was no difference from the result of S-pin and HA2 showed noticeably high score at tensile test compared to HA1. It means that 100nm-width thin coating impedes osseointegration because coating layer is absorbed or delaminated. However, HA2 that has a thick coated-layer didn’t show this opinion. Thus, thicker coated-layer is more suitable than nano-coated ceramics coating. Also, coated material should not be absorbed for better osseointegration. It should be carefully treated for absorbable ceramics and absorbable-width coating due to delamination between bones and osseointegrated side.

The osseointegration strength by chemical bonding between BGS-7 coating layer and bones formed at 2nd week is strong compared to that of bones with S-pin inserted. In conclusion, S-pin coated with bioactive glass-ceramics such as BGS-7 and Cerabone-AW shows high osseointegration strength at 2nd, 4th, 8th week of insertion compared to S-pin without coating. Particularly, BGS-7 shows significantly high osseointegration strength from 2nd week. It is clinically expected that BGS-7 coated S-pin encourages early recovery of body part in surgery and reduces loosening.