MECHANICAL PROPERTIES OF INTERFACES BETWEEN BONE AND STRONTIUM-CONTAINING HYDROXYAPATITE BONE CEMENT UNDER NON-AND WEIGHT-BEARING CONDITIONS BY NANOINDENTATION

INTRODUCTION
Bioactive bone cements show the ability to bone bonding under both non- [1] and weight bearing conditions [2]. However, it is not clear about the effect of weight-bearing on their bone-bonding behavior. Bone is inherently mechanosensitive and responds and adapts to its mechanical environment. The controlled (non-extensive) bone loading has been found to be related to increased bone mineral content, increased bone density, or to controlled bone loss [3]. Besides, bone metabolism can be significantly increased with a resulting increase in bone-implant contact [4]. What is more, significant increase of bone-to-implant contact was also demonstrated under loading conditions than non-loaded conditions [5]. Therefore, it is hypothesized that weight-bearing should play some role in the bone-bonding behavior of bioactive bone cement. To prove this hypothesis, in this study, we used nanoindentation to measure and compare the mechanical properties of interfaces between bone and strontium-containing hydroxyapatite (Sr-HA) bone cement under non- and weight-bearing conditions.

METHODS
A total of 12 New Zealand white rabbits were divided into two groups, 6 in each. In one group, Sr-HA cement was injected into rabbit ilium (non-weight-bearing conditions). Unilateral hip replacement was performed with Sr-HA cement (weight-bearing conditions) in the other. Six months later, all the rabbits were sacrificed. The histological, scanning electron microscopy (SEM) with energy-dispersive X-ray (EDX) analysis, and nanoindentation test were taken to compare the interfaces between cancellous bone and Sr-HA cement under different conditions.

RESULTS AND DISCUSSION
With regard to the mechanical properties, total different patterns were found in the bone-cement interface under different conditions (Fig. 1 and 2): both the Young’s modulus (17.6 GPa) and hardness (987.6 ±39.2 MPa) of the interface under weight-bearing conditions, were considerably higher than those at either Sr-HA cement (5.2 GPa, 265.5 ±39.2 MPa) or cancellous bone (12.7 GPa, 652.7 ±108.4 MPa). On the contrary, under non-weight-bearing conditions, both the Young’s modulus and hardness values at the interface (6.50 GPa; 342.87MPa) were lower than those at the cancellous bone (10.01 GPa; 475.65MPa), but higher than Sr-HA cement (3.27 GPa; 181.40MPa). The results of the mechanical properties of the interfaces were supported by the histological observation and chemical composition. Histological observation showed intimate contact between Sr-HA cement and cancellous bone under both weight-bearing and non-weight-bearing conditions. However, such phenomena as osteoclast-like cells and remodeling lacunae found under weight-bearing conditions (Fig. 3) were not found under non-weight-bearing conditions. On the other hand, the EDX results of our study showed that the content of calcium and phosphorus at the interface under weight-bearing conditions were considerably higher than those under non-weight-bearing conditions. Combined with the histological observation and EDX results, it is suggested that weight-bearing should have positive effect on bone remodeling and mineralization, as far as bone-cement interface is concerned. And this might be the major contribution to the higher mechanical properties of the interface under weight-bearing conditions.

In this study, Sr-HA cement bonded with cancellous bone in rabbit ilium in one group, however, in femur metaphysis in the other. This might be the major limitation to this study. However, as we did not intend to compare directly the data of Young’s modulus and hardness of two interfaces, but the transition from bone to cement through the interface, the influence of different sites should be minor.

In summary, differences existed under different conditions in mechanical properties, histological observation and chemical composition of bone-Sr-HA cement interface. Therefore, the results of this study suggested that weight-bearing has positive effect on the bone-bonding behavior of bioactive bone cement.

Fig. 1: The Young’s modulus and hardness of cancellous bone, Sr-HA cement and the interface under non-weight-bearing conditions as determined by nanoindentation. The mechanical properties at the interface were lower than bone, but higher than Sr-HA cement.

Fig. 2: The Young’s modulus and hardness of cancellous bone, Sr-HA cement and the interface under weight-bearing conditions. The bone/cement interface exhibited a much higher Young’s modulus and hardness than either the cancellous bone or Sr-HA cement.

Fig. 3: Undecalcified section with Giemsa and eosin staining of cancellous bone and Sr-HA cement under weight-bearing conditions. Intimate contact was found without any fibrous layer intervening. Multinucleus cell (white arrow) covered the surface of the cement, and resorbed the superficial layer of the cement. Cement void can be found around. Osteoblast cells are also found nearby to form new bone (black arrow). New bone infiltrated into the Sr-HA cement (left). Numerous remodeling lacunae could be seen close to the cements. Frequently, the cutting cone of these remodeling lacunae was directional and penetrated into the cement surface (black arrows) (right). R: cancellous bone; C: Sr-HA cement; P: prosthesis; Bar=50µm.

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