Design of new generation femoral prostheses using functionally graded materials: A finite element analysis

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Abstract
This study aimed to develop a three-dimensional finite element model of a functionally graded femoral prosthesis. The model consisted of a femoral prosthesis created from functionally graded materials (FGMs), cement, and femur. The hip prosthesis was composed of FGMs made of titanium alloy, chrome–cobalt, and hydroxyapatite at volume fraction gradient exponents of 0, 1, and 5, respectively. The stress was measured on the femoral prosthesis, cement, and femur. Stress on the neck of the femoral prosthesis was not sensitive to the properties of the constituent material. However, stress on the stem and cement decreased proportionally as the volume fraction gradient exponent of the FGM increased. Meanwhile, stress became uniform on the cement mantle layer. In addition, stress on the femur in the proximal part increased and a high surface area of the femoral part was involved in absorbing the stress. As such, the stress-shielding area decreased. The results obtained in this study are significant in the design and longevity of new prosthetic devices because FGMs offer the potential to achieve stress distribution that more closely resembles that of the natural bone in the femur.

Keywords
Finite element analysis, gait, functionally graded material, femoral prosthesis

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Introduction
More than 8,00,000 hip replacements are performed worldwide annually as a means of treating hip degeneration.¹ The study of early stage in vivo femoral prosthesis failure is interesting because it has the potential to reduce to the minimum repeated surgical interventions and revisions, especially in young patients. The most important factors in the femoral prosthesis design that affect the long-term survival of total hip replacement (THR) are femoral prosthesis geometry, material properties, and surface finish.²⁻⁴ Moreover, the failure of hip prostheses is attributed to the differences in the stiffness of the materials used.⁵ High stiffness can cause the problem known as stress shielding around the femoral prosthesis, which in turn leads to bone remodeling.⁵ By contrast, very low stiffness can lead to small migrations of the prosthesis and subsequent microdislocation.⁶ As such, careful consideration of the mechanical properties of the prosthesis has to be one of the main goals in designing prostheses.

Functionally graded materials (FGMs) are the composite materials that consist of two or more portions.⁷ These materials have unique properties that allow them to serve as suitable substitutes for the materials currently used in the production of prosthetic parts and devices. Therefore, FGMs have been proposed as an alternative that can overcome differences in mechanical properties.⁸ The properties of FGMs can be controlled and optimized by distributing volume fractions of different phases in the gradation direction.⁷ A number of studies have been performed on FGMs and their

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shielding. Therefore, FGMs have the potential to be effective biomaterial substitutes in producing a new generation of hip prosthetic parts that are capable of reducing stress shielding, thus increasing the longevity of the replacement and preventing the loosening of the prosthesis.

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**Conflict of interest**

The authors have no conflict of interest.

**References**


