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The effect of cement stiffness and tibia tray material on the stresses developed in artificial knee

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Abstract

A wide range of materials may be used in manufacturing tibia trays of artificial knee replacements. The Young's modulus of the prosthesis is a critical design variable, since it largely determines how the load is transferred, via the cement to the bone.

The current investigation deals with the effect of Young's modulus of the prosthesis and cement and on the stresses developed in the constituents and surrounding bones of artificial knee. Two practical tibia tray materials of diversified Young's modulus were considered in the present work. These showed that increasing the Young's modulus of the prosthesis resulted in weakening the cement layer, while its effect on other constituents is insignificant. A 50% increase in cement Young's modulus resulted in strengthening both the polyethylene and cement layers.

Keywords: Finite element stress analysis; Artificial knee design; Stress distribution

1. Introduction

The human knee is like a hinge joint that moves in a complex arc and allows the human body to twist and move sideways. Normal knee joints consist of a set of bones, called the femur (upper part), patella and tibia (lower pat). For a knee to function normally, the quality of smoothness where each bone moves upon the other becomes important in the function of the knee joint [1–8,11].

Artificial knee replacement is a surgical operation in which the defective knee joint surfaces are replaced completely with an artificial joint. Total knee replacement (TKR), also referred to as total knee arthroplasty (TKA), is a surgical procedure where worn, diseased, or damaged surfaces of a knee joint are removed and replaced with artificial surfaces. Materials used for resurfacing the joint are not only strong and durable but also optimal for joint function as they produce as little friction as possible. The general goal of TKR is designed to provide painless and unlimited standing, sitting, walking, and other normal activities of daily living. With proper care individuals who have had a TKR can expect many years of faithful function.

The major reason why artificial joints may eventually fail is because of loosening where the metal or cement meets the bone, as well as the wear of the polyethylene layer. There have been great advances in extending how long an artificial joint will last, but loosening is a possibility that may require a revision. A prosthesis is usually used with a cement layer to interlock the prosthesis into the bone. Reinforcement of the cement has been proposed to increase its strength and toughness; this will result in increased cement Young's modulus [9]. In order to support the reinforcement approach, its effect on the strength of the cement layer, surrounding bones and other prosthesis constituents should be predicted.

The current investigation deals with one of the most important parameters in controlling the life span of artificial knees, which is the stiffness of tibia tray and the cement layer. Here the finite element technique has been

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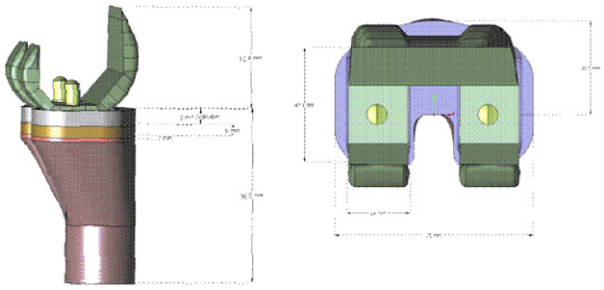

Fig. 1.

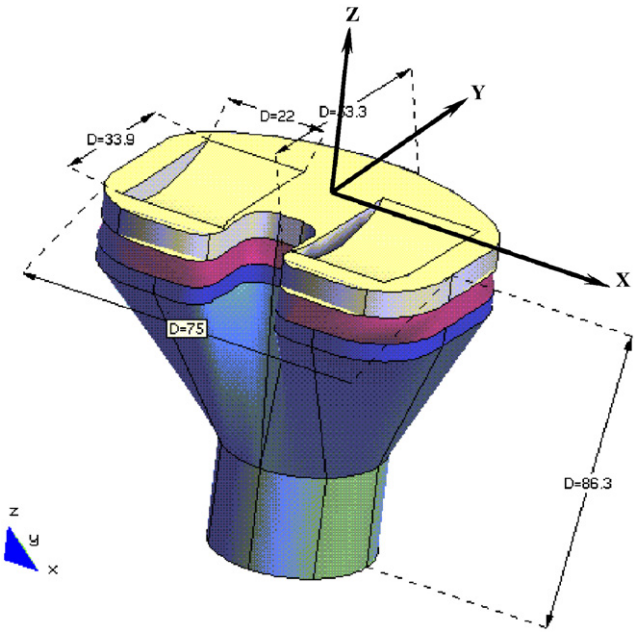

Fig. 2. The configuration and outer dimensions (mm) of the artificial knee joint considered.

adopted to model the prosthesis and its surroundings throughout the evaluation process.

2. Finite element modeling and boundary conditions

The current research was conducted on the cruciate retaining Sigma knee design used in Saudi hospitals [10]. The GID software [12] general-purpose structural finite element program with preprocessing and post-processing was used. Fig. 1 shows the configuration and dimensions of the considered model. The selected cement thicknesses and properties were as used in actual surgery in the King Khaled University Hospital, Saudi Arabia [10]. The finite element model considered along with constraints and loading conditions is shown in Figs. 2 and 3, while Fig. 4 shows full solid and sub-solid models for the knee joint model.

The material properties of the different materials involved are shown in Table 1.

Fig. 3 shows that the lower part of the model is constrained in all directions. The applied load was normally distributed on the bearing area of the polyethylene layer.

Table 1
Material properties of involved materials [11]

Material	Young's modulus (MPa)	Poisson's ratio
Cancellous bone	5.20E+02	0.29
Polyethylene	3.20E+04	0.20
Titanium alloy	1.10E+05	0.36
Plain adhesive (cement)	2.50E+03	0.38
Stiffed adhesive (I)	3.75E+03	0.38
Stiffed adhesive (II)	5.00E+03	0.38
Cortical bone	3.00E+04	0.29
Nickel–chrome alloy	2.00E+05	0.30

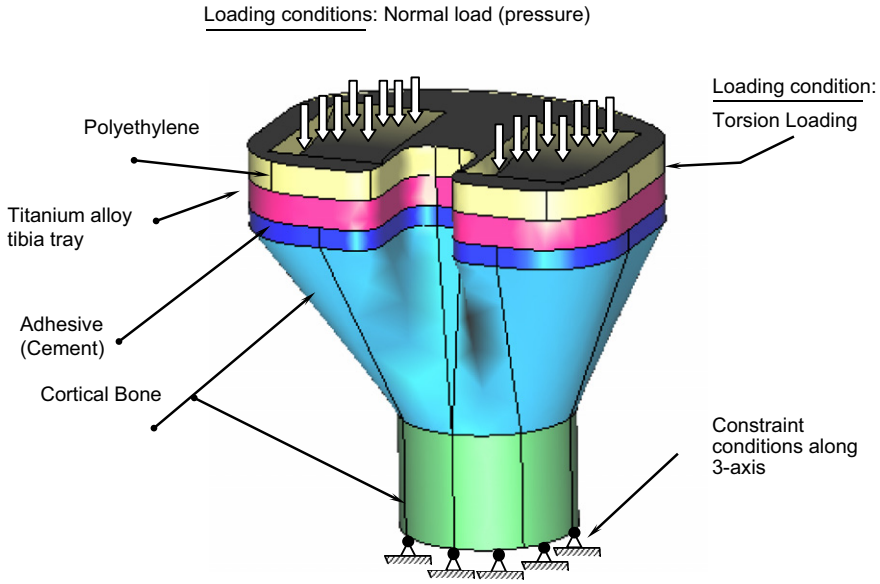

Fig. 3. Assigned material, loading and boundary conditions of FE model.