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A standardized finite element model for routine comparative evaluations of femoral hip prostheses

by R. HUISKES and W. VROEMEN

Biomechanics Section, Laboratory for Experimental Orthopaedics
University of Nijmegen, 6500 HB Nijmegen, The Netherlands,
i.c.w. Department of Fundamental Mechanical Engineering,
Eindhoven University of Technology

Introduction

Finite Element Method (FEM) stress analyses of bone-prosthesis structures have been widely applied for evaluations of prosthetic designs (1), in particular because the characteristics of the load-transfer mechanism in a joint reconstruction have important implications for its longterm survival.

Intramedullary fixated stems have been investigated in this way by several authors, addressing the load-transfer mechanism from a fundamental point of view (2), evaluating design alternatives in general (3), or analysing commercial designs. Routine analyses of actual designs, however, are still relatively tedious and time consuming, whereas results of different authors are not readily compared in view of discrepancies in model characteristics.

The present paper proposes a standardized FEM model for routine evaluations of femoral hip components. The model is two-dimensional to enable cost-effective analyses, but takes the 3-D integrity of the system into account. It is ment to be utilized to evaluate the gross mechanical characteristics of actual designs on a comparative basis. Its application is illustrated with respect to four commercial types, popular in Europe.

Methods

The model uses two superimposed FE-layers of non-uniform thickness (fig. 1), a front-plate and a side-plate to account for the 3-D integrity of the bone. The geometry and thickness variations are derived from

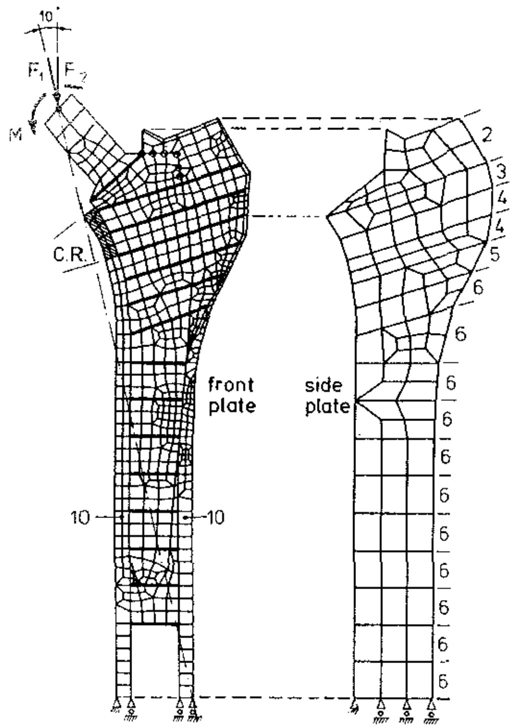
10°
F1
F2
M
C.R.
front
plate
side
plate
10
10
2
3
4
4
5
6
6
6
6
6
6
6
6
6
6
6

FIG. 1.

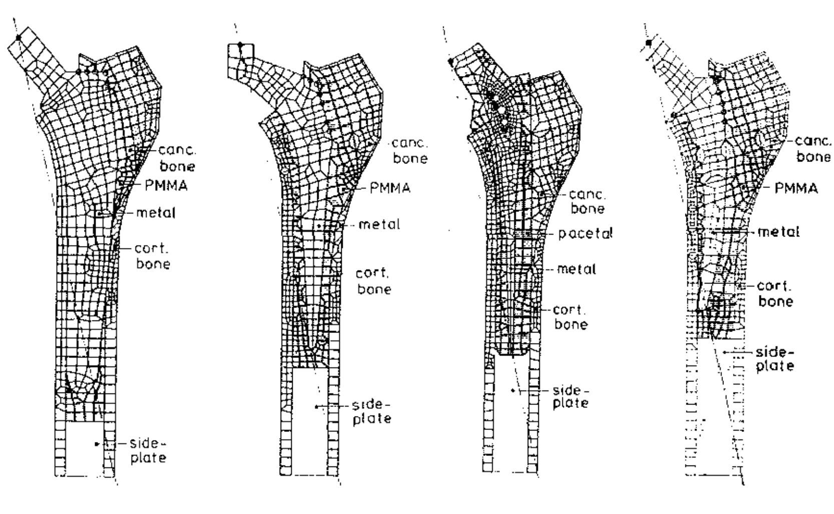
canc.
bone
PMMA
metal
cort.
bone
side-
plate
canc.
bone
PMMA
metal
cort.
bone
side-
plate
canc.
bone
pacetal
metal
cort.
bone
side-
plate
canc.
bone
PMMA
metal
cort.
bone
side-
plate
A
B
C
D

FIG. 2.

a specimen which was sectioned, after strain-gauge analysis was performed. Excellent agreements were obtained between medial and lateral bone-surface strains in the model and the experimental bone, in the intact case. The model is divided in 16 sections (fig. 1) which form the bases for mesh generation in each particular case, and enable stress comparisons between different models in corresponding points. The interface and surface stresses are transformed to align with the surface orientations.

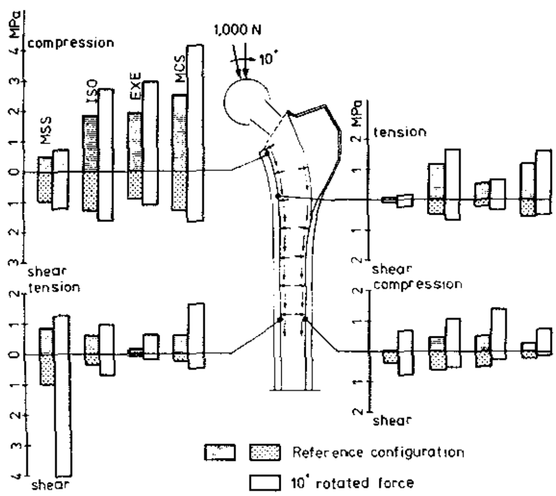

FIG. 3.

Applications

The four commercial designs are coded (fig. 2) MSS (a), EXE (b), ISO (c), and MCS (d). In each case, five calculations are performed, assuming respectively two hip-joint forces and a bending moment (fig. 1), calcar resorption (CR, fig. 1), and titanium versus Co-Cr-steel as prosthetic materials.

Figure 3 shows a comparison of implant-bone interface stresses in the four designs (compression, tension, shear), assuming two different joint loads.

Discussion

The actual stress patterns give usefull information about the mechanical behavior of actual designs. Although unphysiological in nature, pure bending showed to be an excellent coordinate-free load for evaluations of load-transfer mechanisms on a comparative basis.

Notable are the vast differences in stress patterns found for the four designs tested. The results suggest that some designs are far more sensitive to calcar resorption than others. Accordingly, the choice of material is of particular importance in specific types.

An interesting correspondance was seen between some of the interface stress patterns, and clinical experiences reported in relation to specific prostheses.

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