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# Biomechanical evaluation of proximal tibia behaviour with the use of femoral stems in revision TKA: An in vitro and finite element analysis

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ABSTRACT

*Background:* Recognized failure mechanisms after revision total knee arthroplasty include failure of fixation, instability and loosening. Thus, extended stems have been used to improve fixation and stability. In clinical cases where the stem is only applied in the femur, a question concerning the structural aspect of tibia may arise: Does a stemmed femur changes the structural behaviour of proximal tibia? It seems, that question has not yet been fully answered and the use of stems in the opposite bone structure requires further analysis.
*Methods:* Proximal cortex strains were measured with tri-axial strain gauges in synthetic tibias for three different types of implanted femurs, with two constrained implants. To assess the strains at the cancellous bone under the tibial tray, it was considered a closest physiological load condition with the use of finite element models.
*Findings:* No significant differences of the mean of the tibial cortex strains for the stemmed femur relatively to the stemless femur were observed. The $R^2$ and slopes values of the linear regressions between experimental and finite element strains were close to one indicating good correlations. The strain behaviour of cancellous bone under the tibial tray is not completely immune to the use of femoral stem extensions. However, the level of this alteration is relatively small when compared with the strain magnitudes.
*Interpretation:* The main insight given by the present study could probably lie in the fact that the use of femoral stems does not contribute to an increase of the risk of failure of the tibia.


## 1. Introduction

Several studies describe an important decrease in postoperative bone mineral density, closest to the implants, after total knee arthroplasty (TKA) (Li and Nilsson, 2000; Soininvaara et al., 2004). The restoration of lost bone and joint stability are important challenges in revision TKA among others such as proper limb alignment and ligament balance (Bono and Scott, 2005; Mabry and Hanssen, 2007). Bone lost is generally categorized as contained or segmental. Contained defects are surrounded by intact bone, whereas segmental defects have no remaining cortex (Hoeffel and Rubash, 2000). Several clinical options for each bone deficiency category are available for revision surgery. Cement with or without screws, modular or custom augments, and morsellized or structural graft have all been advocated for certain bone deficiencies (Peters et al., 1992; Howling et al., 2001). Morsellized allograft is ideal for smaller contained defects and has been successful in larger defects as long as the component achieves stability on host rim bone (Whiteside and Bicalho, 1998). Structural allograft should be considered in large contained, segmental and combined defects (Clatworthy et al., 2001). Alone, neither of these techniques can give the initial support and stability to the implants in revision TKA. To improve fixation of components, stability and load-share, implants with extended stems have been used in revision TKA (Jazrawi et al., 2001; Rawlinson et al., 2005; van Loon et al., 2000). Revisions TKA are commonly made with posterior-stabilized implants (semiconstrained) when patients present good collateral ligamentous stability (Bono and Scott, 2005) or in the cases where knee stability is not achieved, more constrained devices such as varus–valgus constrained designs are used (Bono and Scott, 2005). Failure mechanisms after revision TKA include collapse of fixation, subsidence, loosening and fracture (Rand et al., 1986). The need of reoperation after revision TKA is approximately 15%, of which nearly 44% may require two or more additional surgeries (Sierra et al., 2003). At revision TKA the fixation of the tibial tray is at risk because of increased bending and torsional loads acting on the implant (Albrektsson et al., 1990; Sharkey et al., 2002). Failure of the supporting cancellous bone in compression is the greatest risk for a well-cemented tibial tray (Burstein and Wright, 1994).

Stem extensions can be used in the femur, tibia or in both bone structures simultaneously depending on the clinical evaluation

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done by the surgeon. In clinical cases where the stem is only applied in the femur, a question concerning the structural issue of the proximal tibia can be raised: Does a stemmed femur change the structural behaviour of tibia with posterior-stabilized or varus–valgus constrained implants, and contribute to loosening of the proximal tibia? The hypothesis here considered lies in the fact that the use of femoral stems should change the structural behaviour of proximal tibia relatively to the stemless femur. All previous studies relatively to either femoral or tibial stems had only analysed the biomechanical parameters in the bone structure where the stem was implanted.

The aim of the present study was to assess how the use of femoral stems with different constrained implants can modify the structural behaviour of the proximal tibia. The study was performed using in vitro and finite element (FE) models. Synthetic femurs and tibiae, commercially available, were used to predict experimentally the biomechanical behaviour of these structures for six implanted configurations. To assess the cancellous bone strains under the tibial tray, it was considered a closest physiological load condition with the use of finite element models and these compared and validated relatively to the experimental strains.

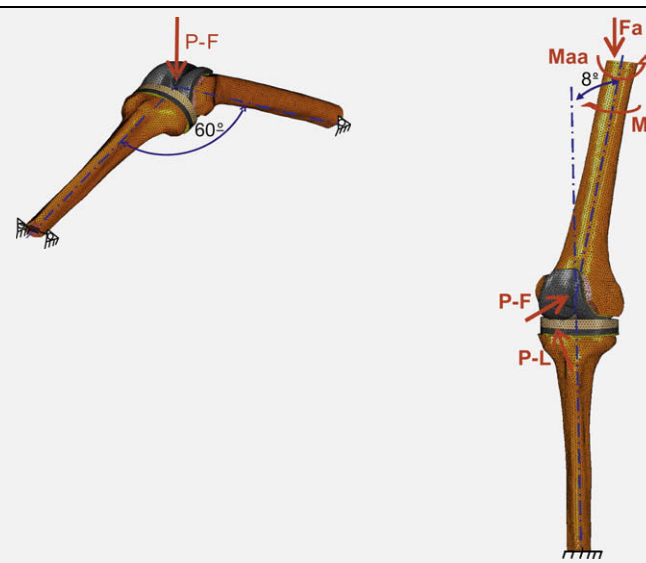
## 2. Methods

Twelve synthetic femurs and five tibiae (mod. 3306 and 3402 from Pacific-Research-Labs, WA, USA) were employed in this study. Two different constraint categories of femoral components, posterior-stabilized (PS) and varus–valgus constrained (TC3), and two femoral stem types (cemented and Press-fit) of the PFC Sigma Knee System (DePuy-International, Johnson & Johnson, Warsaw, USA) were implanted into synthetic femurs: two with no stem, two with a cemented stem and two with a press-fit stem, for each implant category (PS and TC3) (Table 1). Each synthetic tibia was implanted with a tibial tray, common for the two different tibiae inserts, PS and TC3, used with the matching femoral components. The geometrical difference between the two implant constraint categories is the post of the tibial insert and the height of the femoral box. The TC3 type provides a post wider and higher than the post of the PS insert. The in vitro insertion procedures were performed in according with the protocol described for this type of knee prosthesis. The same relative position between the condylar components and bone were attempted in the different models. Bone cement was used for cementing the tibial tray, the femoral component and the cemented stem with a mean thickness of 2 mm.

Six tri-axial strain gauges (KFG-3-120-D17-11L3M2S Kyowa-Electronic-Instruments, Japan) were glued in each one of the five tibiae on the medial, lateral, anterior, posterior and anterior-medial sides of the proximal cortex, adjacent to the tibial tray (Fig. 1). The same position for each strain gauge was kept in the five tibiae using a 3D coordinate measuring machine (Maxim-Aberlink, UK). All strain gauges were connected to a data acquisition system PXI-1050 (National-Instruments, USA). All experimental models

**Table 1**
Schematic representation of load cases analysed with finite element models (flexion angles, values of applied forces and material proprieties).

FE models




| | | | |
|---|---|---|---|
| Load case | 1 | 2 | 3 |
| Flexion angle | 0° | 60° | 8° |
| *Forces and moments applied* | | | |
| Fa (axial force) | 2030 N | – | 2030 N |
| P-F (patella-femoral force) | – | 1746 N | 422 N |
| P-L (patellar ligament force) | – | – | 670 N |
| Mei (internal–external moment) | – | – | 8N m |
| Maa (adduction–abduction moment) | – | – | 40N m |

| Material proprieties of FE models | Elastic module (GPa) | Poisson ratio |
|---|---|---|
| Cancellous bone | 0.155 | 0.3 |
| Cortical bone | 16.7 | 0.3 |
| Tibial tray and stems – Ti–6AI–4V | 110 | 0.3 |
| Femoral component – Co–Cr–Mo | 210 | 0.3 |
| Tibial insert – polyethylene | 0.5 | 0.3 |

| Number of elements of FE models | PS model | TC3 model |
|---|---|---|
| Stemless | 278,965 | 280,249 |
| Cemented stemmed (15 × 90 mm) | 298,020 | 299,568 |
| Press-fit stemmed (18 × 175 mm) | 299,341 | 301,295 |