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Addition of a short central extension to surface cemented tibial trays in primary TKA: An in vitro study of the effect on initial fixation stability and its relationship to supporting bone density

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Abstract

Background. Short central extensions which do not enter the tibial medullary canal are incorporated to cemented tibial components to increase initial stability in primary total knee arthroplasty. Their role in tibiae of differing preoperative mechanical quality has been little studied.

Methods. Twelve embalmed cadaveric tibiae were paired and divided into two groups, receiving a similar cemented tibial component with or without a non-cemented short central extension (10 mm diameter, 35 mm length). The specimens were subjected to 6000 cycles of a medially applied 1350 N load. Relative bone–tray displacements were measured and the evolution of inducible and permanent micromotions were computed. The apparent density of the cancellous bone under the tibial tray and at the area to support the extension was computed from computed tomography images of each specimen.

Findings. No significant differences between groups were detected for any parameters. For the group with extension, a significant negative linear correlation ($P = 0.009$, $r^2 = 0.849$) was found between the inducible tilt of the tray and the bone density at the zone of the extension. Also a trend towards a negative linear relation ($P = 0.07$, $r^2 = 0.59$) was observed for the same group between maximum subsidence and apparent density at the zone of the extension.

Interpretation. The study did not find that the addition of a non-cemented short central extension provides any overall improvement of the initial fixation stability. However, it was found that short extensions may enhance tilting stiffness of the bone–implant construct if bone of sufficient mechanical quality is located around its supporting area.

Keywords: Bone density; Initial stability; Primary total knee arthroplasty; Short central extension; Tibial prosthesis

1. Introduction

Primary total knee arthroplasty (TKA) has a success rate of over 90% after 10 years operation, with an average decrease of 1% per post-operative year thereafter (Robertson et al., 2001). Most significant implant-related post-operative complications concentrate on the tibial component, the main causes being aseptic loosening due to micromotion or to osteolysis caused by wear particles, both resulting in loss of fixation (Gioe et al., 2004).

Some authors have proposed using parameters related to the stress and strain in the bone under the tray in order to asses the level of stability of the tibial component (Perillo-Marcone et al., 2004; Rawlinson et al., 2005; Taylor and Tanner, 1992). In other studies, experimentally measurable parameters related to the relative bone–tray displacements, such as maximum total point motion (MTPM), lift-off, subsidence, tilt and axial rotation of the tibial tray on the bone, have been reported and measured in vivo (Albrektsson et al., 1990; Fukuoka et al., 2000; Li and Nilsson, 2000;

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Nilsson et al., 1991; Ryd et al., 1995; Toksvig-Larsen et al., 1998) and in in vitro (Lee et al., 1991; Lonner et al., 2000; Stern et al., 1997; Toms et al., 2005; Yoshii et al., 1992) at different time intervals. Measurements of early migration during the first two post-operative years can anticipate subsequent loosening of the components (Grewal et al., 1992; Ryd et al., 1995), and it has been reported that the early migration of cemented and cementless components is strongly related to initial micromotion induced by directly applied local loads (Fukuoka et al., 2000; Toksvig-Larsen et al., 1998; Uvehammer and Kärrholm, 2001).

Using a cemented tibial component is the preferred option to increase primary fixation and initial stability, especially in osteoporotic underlying bone. In many successful cemented designs of tibial trays, screws, keels, pegs or intramedullary stems are added to improve initial stability. Several studies have been conducted to assess the role of intramedullary central stems on the stability of the component, but their use and the need to cement them are still matters of controversy, since varying conclusions have been reported (Anderson et al., 2006; Font-Rodriguez et al., 1997; Luring et al., 2006; Peters et al., 2003; Rawlinson et al., 2005; Stern et al., 1997). Some observations have associated the use of stems with a decrease in proximal bone density due to stress-shielding, which may jeopardize long term stability (Lonner et al., 2000). Other important problems associated with the use of intramedullary stems are the invasive bone interference which may complicate revision surgery, mainly if the stem is cemented, the possible appearance of end-of-the stem pain, increased operating time and higher costs of the component.

Short central extensions which do not enter the tibial medullary canal but extend only a few centimeters distally to the tray surface into the cancellous bone are incorporated to many tibial component designs as built-in or modular elements. This option seeks to increase initial stability while at the same time reducing the problems related to intramedullary stems. However, the surgery is still more invasive and time-consuming, the risk of stress-shielding still remains and the cost of the component is higher with the extension than without it. The effect of short extensions on the initial stability of the prosthesis has been little studied experimentally (Lee et al., 1991; Stern et al., 1997). Computer analyzes based on finite element models to study the role of the extension are also limited (Lewis et al., 1982; Shirazi-Adl and Ahmed, 1989) and the high anisotropy and heterogeneity of the trabecular bone of the proximal tibia, whose mechanical characteristics in the area surrounding the extension can strongly influence the role of the extension, was not reproduced in detail in these studies.

The aims of this work are twofold: (a) to analyze the effect of a short cylindrical central extension to enhance initial stability for primary fixation of a surface cemented tibial component with a built-in keel; (b) to study the relationship between initial stability and the mechanical quality of cancellous bone surrounding the extension at the metaphysis, as measured by its apparent density.

2. Methods

2.1. Specimens

Twelve human tibiae with bone density values at the proximal area within the range typically found in the 60 and over population, the group which who most frequently receives TKA, were preserved using the Thiel embalming method (Thiel, 1992). They were paired firstly according to their size, given by their maximum medial–lateral (ML) length and maximum anterior–posterior (AP) length, so that paired tibiae fitted the same size of tibial component; secondary according the mean apparent density of the trabecular bone at the proximal central area to support the extension, established as a cylinder of ∅ 25 mm × 25 mm located at 10 mm below the cut surface along the longitudinal axis of the tibia. The apparent density of the trabecular bone was computed as a linear function of the mean radiological density, measured in Hounsfield units (HU), as it is described below. Table 1 shows the values used to match the tibiae.

2.2. Tibial component implantation

The specimens were dissected free of soft tissue and solidly fixed in a custom-made device. A single expert surgeon performed the tibial cut, using the standard surgical instruments of the selected prosthetic system. By using appropriate templates supplied by the manufacturer, the size of the tibial tray was chosen to provide optimal coverage of the osteotomy surface with maximal cortical support, avoiding both oversizing and undersizing. The final position of the

Table 1
Characteristics of the paired tibiae and of the tibial component that each pair received (without extension/with extension)

Radiodensity (HU)	ML length (mm)	AP length (mm)	Tray size	Contact area (mm^2)	Perimetral support (%)
175.7/216.1	71.3/74.0	49.6/53.3	500	2512.3/2619.8	37.25/76.00
26.0/−55.7	71.2/76.1	51.5/54.6	500	2523.3/2843.8	24.67/30.53
148.8/181.1	73.3/82.9	52.0/57.0	600	2717.9/3175.3	51.31/42.66
45.9/54.5	82.6/81.2	62.0/58.4	600	3139.2/3147.9	44.78/40.31
67.2/77.9	79.3/80.4	56.4/56.5	600	3030.7/2996.8	43.30/43.14
180.0/108.9	81.7/86.0	57.3/60.2	700	3557.21/3533.4	43.24/37.31

Radiodensity: mean radiological density at the central cylinder to support the extension; ML length: maximum medial–lateral length of the tibia; AP length: maximum anterior–posterior length of the tibia; Contact area of the implant; Perimetral support of the implant.