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Primary stability of unicompartmental knee arthroplasty under dynamic flexion movement in human femora

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ABSTRACT

Background: The objective of our study was to evaluate the impact of a trabecular stem fixation versus a cortical teeth fixation technique on the primary stability of cemented unicompartmental femoral components under dynamic flexion movement loading conditions in human femora.

Methods: Ten fresh-frozen human knees of a mean donor age of 73.9 years were used to perform medial unicompartmental knee arthroplasty under a less invasive parapatellar surgical approach. The femora were divided into two groups of matched pairs based on comparable trabecular bone mineral density. To assess the primary stability, a new method based on a combination of dynamic flexion movement, double-peak loading simulating stair climbing, kinematic analysis of the femoral component migration relative to the bone and an evaluation of the cement layer by fragments cut through the implant-cement-bone interface in the sagittal plane of the medial condyle was introduced.

Findings: For the "trabecular stem fixation" technique the mean load to failure was 2340 (SD 650) N and for "cortical teeth fixation" it was 1080 (SD 455) N, with a substantially enhanced dynamic fixation strength for the "trabecular stem fixation" ($p = 0.008$). In the distal area the cement layer of the "trabecular stem fixation" showed a significant decreased thickness compared to the "cortical teeth fixation" ($p = 0.029$), while a substantially deeper cement penetration ($p = 0.044$) has been achieved for the "trabecular stem fixation".

Interpretation: From our observations, we conclude that there is a significantly enhanced primary stability with a "trabecular stem fixation" compared to a "cortical teeth fixation" technique of cemented unicompartmental femoral components, in terms of dynamic failure load and migration characteristics.

1. Introduction

Relieving pain and restoring function of the knee joint, unicompartmental knee arthroplasty (UKA) has to be considered as a successful clinical treatment option for patients suffering from anteromedial osteoarthritis (Argenson et al., 2002; Svärd and Price, 2001; Pandit et al., 2006; Emerson and Higgins, 2008). Advantages of unicompartmental over total knee arthroplasty (TKA), such as minimal invasive surgery without eversion of the patella (Mueller et al., 2004; Price et al., 2001), less blood loss (Aldinger et al., 2004) significantly decreased infection risk (Furnes et al., 2007), faster recovery and earlier discharge (Brown et al., 2012; Lombardi et al., 2009) have been described.

Provided there is appropriate patient selection (Argenson et al., 2002; Murray et al., 1998) unicompartmental knee arthroplasty has shown excellent longterm results after isolated medial gonarthrosis (Berger et al., 2005; Pandit et al., 2011; Price and Svärd, 2011; Steele et al., 2006), in particular in high-volume UKA centers and high-volume UKA surgeons (Baker et al., 2013; Furnes et al., 2005; Price and Svärd, 2011).

However, these promising clinical results are not directly transferable to the average lower volume center or lower volume knee surgeon. Analysing a cohort of 4307 medial cemented Endo-Link and St. Georg UKA's commonly used between 1986 and 1995 in Sweden, Robertsson et al., 2001 found a negative correlation between the the risk of revision and the number of UKA treatments performed in a clinical center per year. The surgical units doing <23 UKA's/year ($n = 1027$) had a 1.53 times higher risk of revision than the surgical units performing ≥23 UKA's/year ($n = 3280$). Evaluating data from 5791 UKA procedures registered from 1999 to 2012 in the Norwegian Arthroplasty Register Badawy et al., 2014 reported the influence of the hospital procedure

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volume on the risk of revision based on a sub-cohort of 4460 medial Oxford III UKA's. They divided the analysed cohort in four volume groups (1–10, 11–20, 21–40, >40) and found that the unicompartmental knees in the 21–40 and the 11–20 volume groups had a lower risk of revision than those in the 1–10 procedures group, whereas the >40 UKA procedures group had the lowest risk of revision. These joint registry findings demonstrate that unicompartmental knee arthroplasty is a technically demanding surgery, sensitive to surgical experience (Bonutti and Dethmers, 2008) and requires a substantial learning curve (Hamilton et al., 2009). Due to this an UKA implant fixation method should be somehow robust in clinical practice.

Price et al., 2005 found in a comparison of UKA results in patients younger and older than 60 years of age a ten-year survival rate of 91% (<60 years) and of 96% in the ≥60 years of age group. Kuipers et al. (2010) report a greater risk of revision in patients younger than 60, and Parratte et al. (2009a) survival rate at 12 years of 80.6% in a cohort of 31 UKA patients younger than 50, aseptic loosening being the main cause of failure in young and active patients. In joint registries, the results of UKA were inferior to those of tricompartmental knee arthroplasty (Furnes et al., 2007; Lyons et al., 2012). Lewold et al., 1998 analysed the outcome of 1135 revision cases of unicompartmental knee arthroplasties recorded between 1975 and 1995 in the Swedish Knee Arthroplasty Register, where 232 revisions were performed again as UKA and 750 as a total knee replacement. Already after 5 years the cumulative re-revision rate for failed UKA's revised to a new UKA was 26%, more then 3-fold higher than for those revised to a TKA (7%). They concluded that UKA is a safe primary procedure, but once failed the knee should be revised to a TKA (Lewold et al., 1998). Pietschmann et al., 2014 reported that medial UKA with tibial bone defects can be revised to an unconstrained TKA using an autologous bone slice from the lateral proximal tibia resection.

In the Knee Arthroplasty Register of the Australian Orthopaedic Association 3359 UKA procedures failed between 1999 and 2011 were reported and 85% have been revised to a TKA (n = 2840), 1.5% to a UKA again and 6.5% with a partial UKA tibial or femoral component (Graves et al., 2012). For primary UKA undertaken for osteoarthritis the cumulative percent revision at 11 years was 16.4% with aseptic loosening/osteolysis as main reasons for revision followed by progression of disease (Graves et al., 2012).

Saldanha et al., 2007 evaluated in a multicenter study a cohort of 1060 UKA procedures during a 15 year period with 36 UKA's failed due to aseptic loosening and revised to a total knee replacement. They found that in 30 cases reconstruction for bone loss was not required, whereas in the others metal or cement augmentation and bone grafts from revision cuts were used and pointed out the importance of bone stock preservation during primary UKA fixation (Saldanha et al., 2007).

Furnes et al., 2007 evaluated the rates of failure of primary cemented unicompartmental (n = 2288) and tricompartmental (n = 3032) knee replacements as reported to the Norwegian Arthroplasty Register in period from 1994 to 2004. They found a 10-year survival probability of 80.1% for unicompartmental compared with 92.0% for tricompartmental knee arthroplasties. Beneath an increased risk of revision due to pain (relative risk 11.3-fold) and periprosthetic fracture (3.2-fold), they reported a 1.9-fold increased relative risk for aseptic loosening of the tibia and of 4.8-fold for the femur as compared to total knee replacement

Therefore loosening of the femoral component is one of the main reasons for revision in cemented unicompartmental knee replacements (Furnes et al., 2007). To assess the primary stability of femoral components in vitro, different approaches had been undergone: cement penetration depth analysis (Vaninbroukx et al., 2009) or examination of the femoral fixation pattern at the implant-cement-bone interfaces using lateral radiographs and morphological bone cuts regarding cement mantle, interdigitation and subchondral bone sclerosis areas (Clarius et al., 2010), but the primary stability has not been measured in a biomechanical test setup. Cristofolini et al., 2009 implanted clinically established TKA cobalt-chromium components in composite femurs and compared them to Biolox® delta ceramic components in a knee simulator test by recording inducible micromotions and permanent migrations to assess the implant fixation. However, these test conditions in composite femora are focused on the implant-cement interface, whereas a strong cement-bone bonding was ensured in the in vitro model not dedicated to fail. In addition due to the ISO 14243 profiles applied in a knee wear simulator the loading was limited to level walking with a peak at 15° flexion. To simulate demanding physiologic loading conditions for stair climbing for the current test series the idea came up to subject the unicompartmental femoral component to combined double-peak axial compression and shear forces under a dynamic flexion movement based on in vivo data (Bergmann et al., 2010; Bergmann et al., 2014; Kutzner et al., 2010).

2. Objectives

The objective of our study was to evaluate the impact of a “cortical teeth fixation” versus a “trabecular stem fixation” technique on the primary stability of cemented unicompartmental femoral components under dynamic flexion movement loading conditions in human femora.

3. Methods

We performed a medial UKA under clinical conditions on ten fresh-frozen human knees of a mean donor age of 73.9 years (range 52–90) with the distal third of the femur and the proximal third of the tibia and intact surrounding tissue. To determine bone mineral density (BMD) CT-scans (Sensation 64 Somatom, Siemens Munich, Germany) were made of all tibiae prior to the implantation. The BMD was determined on the medial tibial head in 7 layers of 3 mm thickness in the region of trabecular bone, using a relative calibration to water (0 Hounsfield units (HU)) and calcium (200 HU). We divided the femora into two groups of matched pairs (Table 1).

A less invasive parapatellar surgical approach without eversion of the patella with a 7–8 cm skin incision was chosen. The bone preparation and implantation of the femur, the tibial plateau and the gliding surface was done as described in the OR manual (Univation® F for

Table 1
Human knee specimen characteristics, bone mineral density, implanted version and femoral component size.

Specimen	Sex	Age	Leg (medial)	BMD [mg/mm^3]	Bony fixation technique	Femoral component size
K01B	Male	83	Left	84	“Cortical teeth”	F4LM
K01A	Male	83	Right	79	“Trabecular stem”	F4RM
K02A	Female	84	Right	67	“Cortical teeth”	F3RM
K02B	Female	84	Left	76	“Trabecular stem”	F2LM
K03A	Male	52	Left	87	“Cortical teeth”	F1LM
K03B	Male	52	Right	89	“Trabecular stem”	F2RM
K04A	Male	69	Right	119	“Cortical teeth”	F4RM
K07A	Male	58	Right	117	“Trabecular stem”	F4RM
K06A	Female	84	Left	86	“Cortical teeth”	F2LM
K09B	Male	90	Right	135	“Trabecular stem”	F4RM