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Effect of minimally-invasive implantation of unicompartmental knee arthroplasty on cement penetration and biomechanical stability. An experimental study in human tibiae

C. Scheele[b,*,1], M.F. Pietschmann[b,1], C. Schröder[c], T. Grupp[a,b], M. Holderied[a], V. Jansson[b], P.E. Müller[b]

[a] *Aesculap AG Research & Development, Am Aesculap-Platz, 78532 Tuttlingen, Germany*
[b] *Ludwig Maximilians University Clinic for Orthopaedic Surgery, Campus Grosshadern, Marchioninistr. 15, 81377 Munich, Germany*
[c] *Ludwig Maximilians University Laboratory for Biomechanics and Experimental Orthopaedics, Campus Grosshadern, Feodor-Lynen-Straße 19, 81377 Munich, Germany*

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ABSTRACT

Background: Unicompartmental knee arthoplasty is a well-established treatment modality for anteromedial osteoarthritis and can be implanted minimally-invasive. However, the operation is technically demanding, which might lead to an increased failure rate. This study was conducted to determine the influence of a minimally-invasive approach on biomechanical fixation strength and morphological cement penetration.
Methods: Tibial unicompartmental knee arthroplasties were implanted in 8 cadaver knees. On the medial side, implantation was performed minimally-invasive (group A). The lateral side was operated in an open way (group B). Biomechanical stability was testes using dynamic compression-shear load to failure. Cement penetration was analyzed on serial cuts through the implant–cement–bone interface in the frontal plane.
Findings: Mean load to failure was 2438 N (SD 968 N) in group A and 2231 N (SD 1044 N) in group B ($P = 1.0$). The area proportion of the cement–bone interface without cement penetration was 24.2% (SD 18.8%) in group A and 7.7% (SD 5.9%) in group B ($P < 0.05$). In group A, cement mantle increased in thickness from 0.21 mm (SD 0.18 mm) in the anterior section of the tibial head to 1.35 mm (SD 0.33 mm) in its posterior section ($P < 0.0001$).
Interpretation: The study demonstrates no inferiority of minimally-invasive surgery with respect to fixation strength. However, the higher area proportion of the cement–bone interface without penetration and the increasing thickness of cement mantle from anterior to posterior indicate further room for improvement of the minimally-invasive approach in unicompartmental knee arthroplasty.

1. Introduction

Unicompartmental knee arthroplasty (UKA) is a well-established treatment option for patients suffering from anteromedial osteoarthritis of the knee. The literature reports 10-year survivorship of up to 98% as well as excellent functional results (Emerson et al., 2016; Foran et al., 2013). Compared to TKA, UKA offers the preservation of soft tissue, bone stock and the cruciate ligaments, and can be implanted in a minimal invasive approach, which is performed through a short incision medial to the patellar tendon, without dislocation of the patella. This results in a shorter recovery period, an extended range of motion and a more physiological functioning of the knee (Price et al., 2001; Newman et al., 2009; Repicci & Eberle, 1999).

However, these favorable results are dependent on a proper patient selection and experienced surgical skills (Repicci & Eberle, 1999; Zambianchi et al., 2015). The limited access to the operation field and the reduced number of surgical landmarks are considered to make positioning and alignment of the components more difficult using minimally-invasive surgery (Muller et al., 2004; Kort et al., 2007). Whereas Price et al. (2001) and Muller et al. (2004) denied any loss of accuracy during implantation, Fisher et al. (2003) showed cases of worse positioning of the prosthesis using a minimally-invasive approach. In conclusion, minimally-invasive surgery of UKA is generally regarded as technically demanding and might contribute to the increased failure rate of UKA compared to TKA (Kort et al., 2007; Robertsson et al., 2001; Epinette et al., 2012; Zhang et al., 2014).

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* Corresponding author at: Klinikum rechts der Isar, Technical University of Munich, Department of Orthopedics and Sports Orthopedics, Ismaninger Str. 22, 81675 Munich, Germany.
E-mail address: C-Scheele@web.de (C. Scheele).

[1] Both authors contributed equally.

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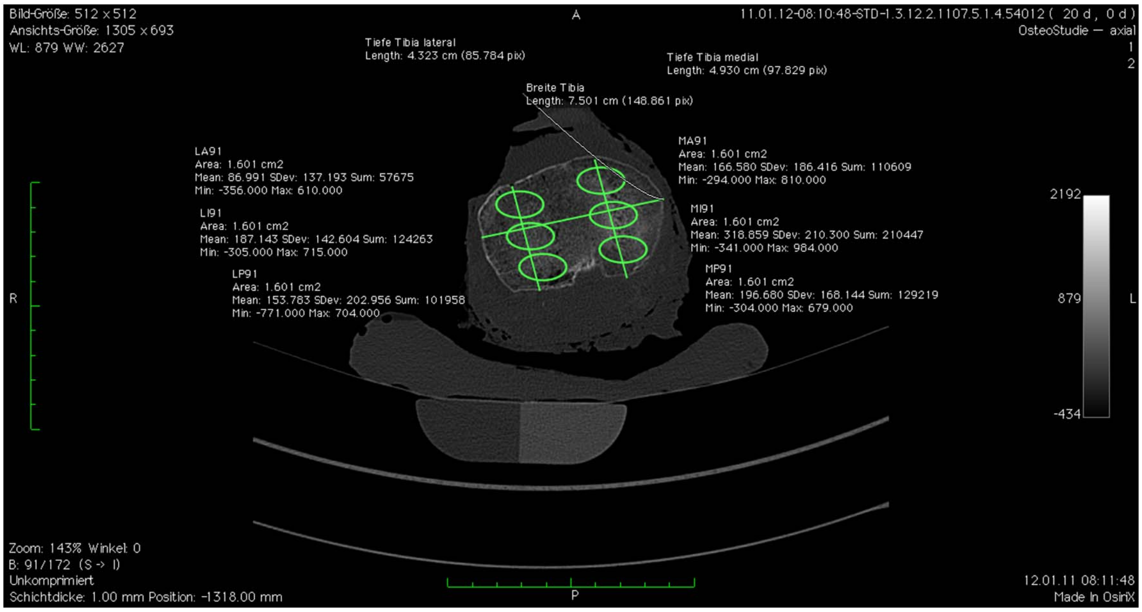

Fig. 1. Measurement of bone density in 6 regions of the tibial head and determination of the required implant size.

The objectives of this study were to evaluate the effects of a minimally-invasive approach on 1) biomechanical stability of tibial components and 2) on morphological cement penetration, compared to a control group that was implanted in an open way. Our hypothesis was that both implantation techniques lead to identical biomechanical stability and result in an equivalent, equally-distributed cement penetration.

2. Methods

To exclude cadaver knees with osseous anomalies and to ensure comparability between groups, CT-scans of all tibiae were performed prior to implantation (Sensation 64 Somatom, Siemens Munich, Germany). Local bone density was determined by measuring the mean Hounsfield units of 6 regions of interest (ROI), each of 1.6 cm^2, in the tibial head. The six ROIs represent the anterior, middle and posterior section of the lateral and medial tibia plateau (Fig. 1). To capture the area of implantation, the measurement was conducted in 20 layers of 1 mm thickness, starting in the most cranial slice without visible bone sclerosis.

Thereafter, medial and lateral UKAs were implanted in eight fresh-frozen human knees with a mean donor age of 70.1 years (range 53–84). First, the medial side was implanted via a minimally-invasive approach (group A). Then the lateral UKA was implanted unsing an open technique after dissecting the joint (group B; see Table 1). All implantations were performed by the same experienced surgeon according to the manufacturer's instructions. The minimally-invasive implantation (group A) was conducted using a 7 cm incision from the medial pole of the patella to the tibial tuberosity without eversion of the patella. After the appropriate implant size was verified, horizontal resection was performed 7 mm below the joint line with an anatomical posterior slope. Bone preparation was performed using a pulsed water lavage (Pulsavac® Plus, Zimmer, USA) with 500 ml volume and 2 min purging time. High viscosity bone cement (Palacos® R 20 g powder/10 ml monomer, Heraeus Medical Wehrheim, Germany) was chosen for fixation of the implants (Univation® F, Aesculap Tuttlingen, Germany), and manually mixed. Approximately 10 g of cement were applied by hand on the inferior surface of the tibial component, while the trabecular resection surface was left cementless. Each tibial tray was carefully placed and impacted onto the tibia using the manufacturer's impactor (Univation® F instruments, Aesculap Tuttlingen, Germany). The knee was positioned in 45° flexion for pressurization during the PMMA cement polymerization process, and a spacer was inserted to maintain the compression until the cement was completely cured. Afterwards, the lateral UKA was implanted in an open way, using the same bone preparation and technique cementing (group B).

Table 1
Table displays gender composition, age distribution and bone density (measured as Hounsfield Units).

Number of knees (left/right)	8 (3/5)
Gender (male/female)	6/2
Age [years] (min-max)	70.6 (53–84)
Bone density [Housfield Units]	143.0 SD 38.6

To assess biomechanical stability, the surrounding soft tissue was removed and the specimens were aligned in the sagittal plane to the tibial axis in 0° extension, and embedded with polyurethane casting resin in metal cylinders, 70 mm distally from the anterior tibial tray surface. Thereafter, the tibiae were fixed on the hydraulic testing machine (DYNA-MESS Prüfsysteme Stolberg, Germany), in a flexed position of 15°. During the dynamic testing, an initial load of 1500 N was applied for 1000 cycles followed by a stepwise load increase (Locati steps of 300 N, 1000 cycles) until failure or termination of the test at the highly demanding final load level of 4200 N. The criterion for load to failure was set to a maximal movement increase in the medial knee joint articulation of 0.4 mm at a single load level. The implants remained firmly fixed to the bone after finalization of the load regime to permit the subsequent morphologic analysis of cement penetration.

To analyze the cement layer morphologically, the specimens were first dissected in the sagittal plane in the region of the eminentia intercondylaris, 20 mm transversally below the tibia plateau. Thereafter, they were embedded (Technovit 4004, Heraeus Medical Wehrheim, Germany) in rectangular metal tubes (WxDxH: 50 × 110 × 30 mm). This was done utilizing a custom-made aligning device, to ensure correct orientation and position of the specimen during the cutting process. The specimens were then cut in the frontal plane into ten slices of identical thickness for each size of the tibial component. Therefore, master plates, which had been designed using CATIA (Dassault Systèmes Vélizy-Villacoublay, France) and purpose-made of polylactic acid in a rapid prototyping 3D-printing process (Ultimaking Geldermalsen; Netherlands) were used. The speed of the cutting-off machine (Conrad Apparatebau GmbH, Clausthal-Zellerfeld, Germany)