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KNEE ARTHROPLASTY

The influence of the femoral force application point on tibial cementing pressure in cemented UKA: an experimental study

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Abstract
Background Aseptic loosening is the major cause for implant failure in cemented unicompartmental knee arthroplasty (UKA). Central positioning of the femoral pressure during the tibial cementation process is recommended to achieve equal pressure and a good cementation result. The aim of this study was to verify the central position of the femoral force application point (FFAP) at 45° flexion of the knee and to investigate the influence of ligament tension and cement penetration pressure (CPP) for UKA.
Materials and methods Cemented Oxford UKAs were performed in 24 human legs. CPP and ligament tension forces (LTF) were measured. The FFAP was measured in a standardised manner in relation to the tibial implant length on lateral digital X-rays.
Results The FFAP at 45° of knee flexion is located at 53.5 % and is not significantly different from the FFAP at 0° ($p = 0.768$). The CPP shows mean values at the anterior portion of 13.97 kPa (SD 16.11), at the implant keel of 24.34 kPa (SD 25.21) and at the posterior portion of 36.58 kPa (SD 26.51). The LTF shows a mean value of 194.35 N (SD 83.77).
Conclusion The central position of the FFAP for the investigated cemented UKA with single radius femoral component at 45° flexion of the knee could be confirmed. A flexion angle of <45° does not influence the position of the FFAP significantly. More than 45° of flexion should be avoided because the FFAP shifts backwards significantly and may cause increased pressures posteriorly and therefore tilting of the component occurs during the cementation process.

Keywords Unicompartmental · UKA · Cementing technique · Pressure · Ligament tension

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Introduction

Unicompartmental knee arthroplasty (UKA) with fixed or mobile bearing is a good treatment option for patients with anteromedial osteoarthritis of the knee joint [1–3]. Primary UKA accounts for 11.3 % of all knee replacements. Implant loosening continues to be a major cause for implant failure in UKA with 48.3 % of all failures [4]. A continuous, homogenous cement layer and good anchorage in the bone bed are necessary to ensure stable, long-lasting implantations [5]. The durability of cementation is dependent on the penetration pressure. Due to anatomical reasons and the minimally invasive approach, pressure can only be applied through ligament tension, so that the femoral force application point (FFAP) appears to be crucial. The FFAP is the contact point between the femoral and flat tibial component. However, the influence of the FFAP, the ligament tension and the cement penetration pressure (CPP) under the tibial implant in Oxford UKA has not been studied to date.

Cement setting is recommended and routinely performed at 45° flexion of the knee to achieve an equal force distribution on the tibial component. It is assumed that the FFAP is located at the Centre of the tibial plateau. A feeler gauge of the appropriate size is used to tense the medial collateral ligament and apply force on the femoral and tibial component. The aim of this study was to verify the central position of the FFAP at 45° flexion of the knee and to investigate the influence of ligament tension and CPP. We hypothesised that the FFAP is located centrally on the tibial plateau and the cement penetration pressure is uniformly distributed under the tibial implant.

Materials and methods

Ethics

This study was approved by the institutional university review board, as well as by the local ethics committee.

Experimental setup

In an experimental study, cemented Oxford UKA was performed in 24 human cadaver legs by an experienced orthopaedic surgeon according to the surgical technique manual (Oxford Phase III, Biomet, Bridgent, UK). Bone cement (Refobacin Bone Cement R, Biomet, Swindon, UK) was used after vacuum mixing (OPTIVAC M®, Biomet Cementing Technologies AB, Sweden) with a standardised cement timing at a mean room temperature of 21.3 °C ± 0.7 °C. All implants were cemented by the same investigator. After preparing and cleansing the bone bed vacuum cement mixing was started. Cement was applied 120 s after start of mixing to ensure to be in the application phase. According to the author's surgical manual and clinical practise, the keel slot was filled with bone cement and a layer of cement was spread over the tibial component surface. The tibial component was impacted 210 s after start of mixing. Afterwards, the knee was flexed at 45° and the feeler gauge was inserted. For each human cadaver leg, a new implant was used.

Cement penetration pressure was measured using a custom made sensor device. Three miniature pressure probes (XPR36/XAM, disynet GmbH, Brueggen, Germany) were integrated into cylindrical drill holes and fixed into the device. The cement pressure was measured during polymerisation at three standardised positions: posterior, anterior and at the implant keel (Fig. 1). The ligament tension force (LTF) was measured using a specially developed feeler gauge of the appropriate size in combination with an integrated force probe (probe 8413-1000 1 kN, Burster GmbH & Co.KG, Gernsbach, Germany) in a position of 45° knee flexion after placing the implant (Fig. 2). The cement penetration pressure and LTF were recorded continuously during polymerisation of the bone cement using a custom-developed measurement software with a sample rate of 2 kHz.

Determination of femoral force application point

The FFAP in relation to the tibial implant length was measured in a standardised manner on lateral digital radiographs using CAD software (Autodesk Inventor Professional 2008, Autodesk Inc.). All radiograph assessments were performed in a standardised manner under

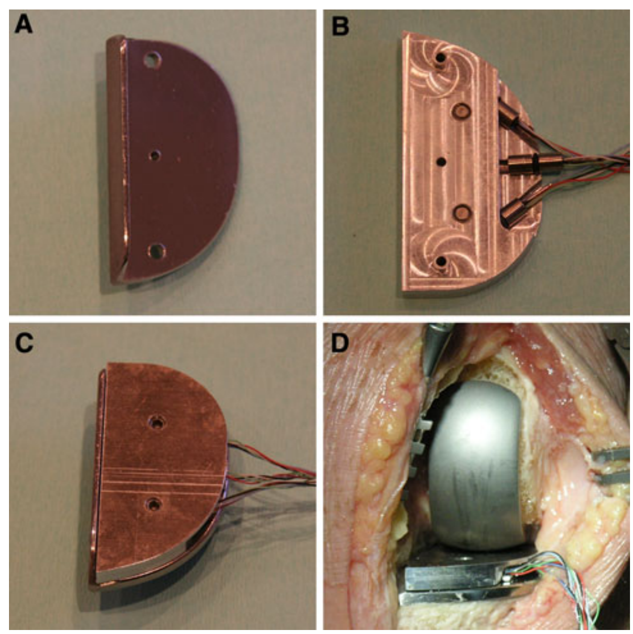

Fig. 1 **a** Implant with measurement positions: posterior, anterior and at the implant keel; **b** sensor device with three miniature pressure probes; **c**, **d** implant with sensor device and integrated sub-miniature pressure probes

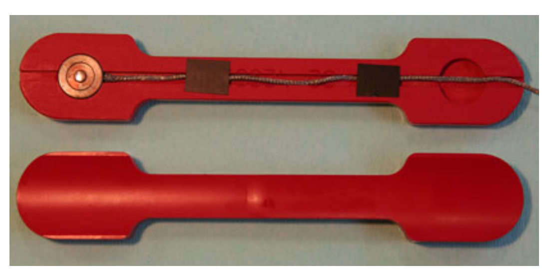

Fig. 2 Feeler gauge with integrated force probe

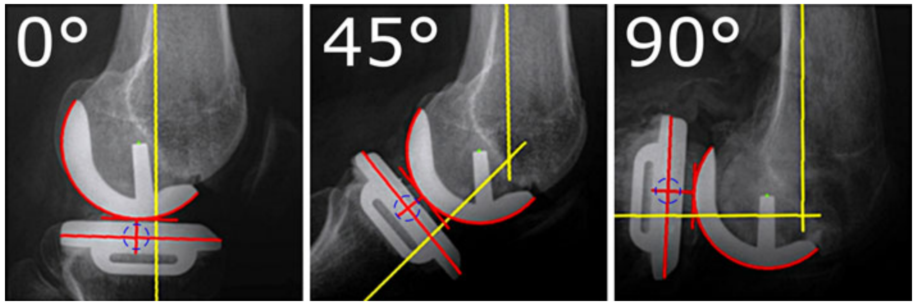

Fig. 3 Position of the femoral force application points (FFAP) on the tibial implants at 0°, 45° and 90° flexion

fluoroscopic guidance. Exact lateral X-rays were taken with the knee at 0°, 45° and 90° of flexion and the X-ray beam centered on the femoral component.All FFAP analyses were performed twice by two different orthopaedic surgeons to determine the inter-observer and intra-observer reliability.

First, the length of the tibial implant was measured and defined as 100 % (anterior margin = 0 %, posterior margin = 100 %). Second, the contour of the femoral component was outlined as a sector. Third, the tangent to the sector was drawn parallel to the surface of the tibial plateau. Fourth, a line through the intercept point was drawn orthogonally to the tibial implant. The intercept point of this orthogonal line and tibial implant was defined as FFAP (Fig. 3).

Statistics

The data obtained were analysed with non-parametric statistical hypothesis Wilcoxon test and Bowker's test for symmetry. In addition, Spearman correlation was used to analyse dependence between two variables. The significance level was fixed at $\alpha = 0.05$. All radiographic analyses were performed twice by two independent experienced examiners to calculate the Kappa correlation coefficient (κ) for the intra- and inter-observer reliability. Statistical evaluation was performed using the analytical software SPSS® for Windows®, version 17.0 (SPSS Inc., Chicago, IL, USA).

Table 1 Position of the femoral force application points (FFAP) on the tibial implants in relation to the percentage of tibial implant length (0 % means the anterior rim)

$n = 24$	FFAP at 0° (%)	FFAP at 45° (%)	FFAP at 90° (%)
Mean	53.4	53.5	59.8
SD	6.1	5.8	7.1
Median	53.8	53.8	59.6
Range (min–max)	41.5–66.4	43.4–64.0	46.9–74.9

Table 2 All measurements were performed twice by two independent experienced examiners to calculate the Kappa correlation coefficient (κ) for the intra- and inter-observer reliability

	0° flexion of the knee	45° flexion of the knee	90° flexion of the knee
κ intra-r	0.996 ($p < 0.001$)	0.989 ($p < 0.001$)	0.995 ($p < 0.001$)
κ inter-r	0.976 ($p < 0.001$)	0.966 ($p < 0.001$)	0.992 ($p < 0.001$)

Results

The positions of the FFAPs at 0°, 45° and 90° knee flexion of the analysed X-rays are shown in Table 1. The mean position between the FFAP at 0° (53.4 %) and 45° (53.5 %) knee flexion is not significantly different ($p = 0.768$). In contrast, the mean position between the FFAP at 45° (53.5 %) and 90° (59.8 %) knee flexion is significantly different ($p < 0.001$). The mean position of the FFAP in relation to the percental tibial implant length at 45° knee flexion shows a slight divergence from the central position of 3.5 % in the posterior direction.

For all X-ray analyses, the intra-observer reliability (intra-r) and inter-observer reliability (inter-r) at 0°, 45° and 90° flexion of the knees are shown in Table 2. The CPP at the anterior mark, at the implant keel, and at the posterior mark is shown in Table 3 together with the LTF. The mean CPP at 45° knee flexion between the measurement points anterior (13.97 kPa) and at the implant keel (24.34 kPa) is not significantly different ($p = 0.160$). The CPP between the measurement points at the implant keel (24.34 kPa) and posterior (36.58 kPa) at 45° knee flexion is significantly different ($p = 0.039$). The location of the maximal cement penetration pressure corresponds to the location of the FFAP (Bowker's Kappa $\kappa = 0.502$) in two-third of cases (Fig. 4). In 13 of 24 cases, the location of the maximum CPP was at the posterior measuring point, seven times at the implant keel and four times at the anterior measuring point. The force, as applied through the ligament tension at 45° flexion during cement polymerisation, has no significant influence on the CPP anterior ($p = 0.843$) and at the implant keel ($p = 0.546$). At the posterior measurement point, the LTF has a significant influence on the cement penetration pressure ($p = 0.044$) (Fig. 5).

Table 3 Cement penetration pressure (CPP) and ligament tension force (LTF) at 45° flexion during cement polymerisation

$n = 24$	LTF (*N*)	CPP anterior (kPa)	CPP implant keel (kPa)	CPP posterior (kPa)
Mean	194.35	13.97	24.34	36.58
SD	83.77	16.11	25.21	26.51
Median	176.13	5.03	16.03	31.57
Range (min–max)	88.55–413.58	0.0–45.79	0.01–87.63	1.36–85.15

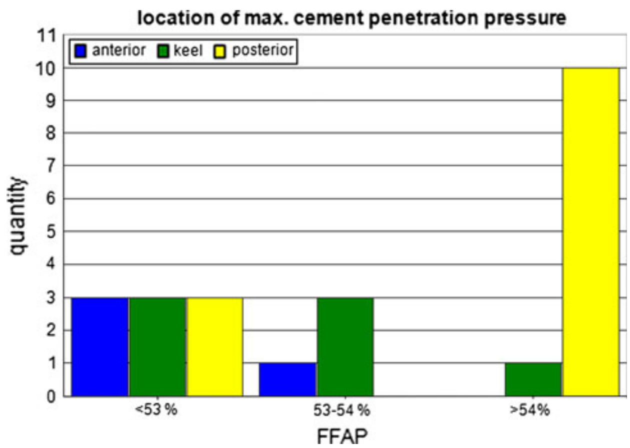

Fig. 4 Quantity of specimens according to the location of their femoral force application points (FFAP) and the location of maximal cement penetration pressure. FFAP <53 % means an anterior location, FFAP = 53–54 % means the mid position on the tibial plateau and FFAP >54 % means a posterior location

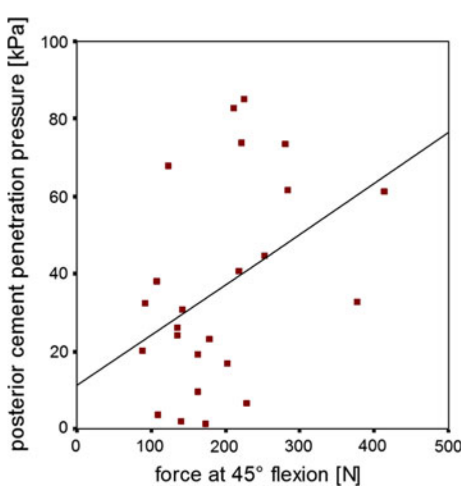

Fig. 5 Posterior cement penetration pressure and ligament tension force

Discussion

Cemented UKA is an accepted treatment option for patients with anteromedial osteoarthritis of the knee. Good clinical and functional results have been reported in the literature [1, 3, 6–10], but in 48.3 %, loosening is a major cause for implant failure in UKA [4]. Aleto et al. [11] reported that in the majority of cases, the mode of failure for medial UKA was a mechanical collapse and 46 % of these cases failed in <16 months. The second most frequent cause of failure was aseptic loosening. In order to achieve a good long-term result, a homogenous cement mantle of enough thickness around the tibial component is recommended to distribute the load into bone.

This study demonstrates the influence of FFAP and LTF on tibial CPP in UKA. The empirical assumption that the FFAP is positioned centrally on the tibial plateau at 45° knee flexion could be confirmed with a divergence of 3.5 %. Our data show a mean FFAP of 53.5 % and a backwards movement of the FFAP between 45° and 90° flexion of the knee. Between 0° and 45° of knee flexion, the FFAP does not change significantly ($p = 0.768$). These data suggest that the knee should preferably be extended rather than flexed out of the 45° flexion position, to confirm a central position of the FFAP during the polymerisation process [12].

It has to be considered that the investigated UKA combines a single radius femoral component design with a fully congruent mobile polyethylene inlay and flat tibia. This single radius design of the femoral component does not coincide with the natural medial femoral condyle. The anatomical medial femoral condyle is polyradial with a posterior radius of curvature smaller than the inferior radius. The single radius femoral component is not coinciding with the natural medial articular surface at the anterior part but is proximal to fit. A constant ligament tension during extension and flexion is maintained to ensure consistent pressure through the mobile bearing [12]. A comparison between single radius femoral components with mobile bearing and polyradial femoral components with fixed bearing showed under force-controlled simulation according to ISO 14243-1:2002, a significantly larger AP translation for the polyradial femoral component with fixed bearing [13]. Therefore, the investigated FFAP and the pressure distribution under the tibial implant could be differing for polyradial unicompartmental femoral components.

Our findings show that with flexion of the knee, a backwards movement of the FFAP acting on the single radius femoral component UKA can be seen, which corresponds to what is seen in healthy knee joints [14, 15]. Goodfellow et al. [14] showed that the obligatory excursion of the contact area of human cadaver knees in extension and flexion is between 0.8 and 1.2 cm. The intact ligament structures, which can be preserved in UKA, seem to be responsible for physiological FFAP movements [16–19]. Studies by Iesaka et al. [20] and Sawatari et al. [21] suggest that the FFAP position in the coronary plane has a severe impact on long-term compressive load and implant survival. In two-third of the specimens, the location of maximal CPP corresponds ($\kappa > 0.5$) to the location of the FFAP (Fig. 4). Our data show a gradient in cement penetration pressure with low values at the anterior measuring point to high values at the posterior measuring point of the tibia. The LTF has a significant influence on the posterior cement penetration pressure ($p = 0.044$). The manner in which CPP and cement penetration might influence the primary stability in UKA merits further examination.

Our study has various limitations. With a mobile bearing UKA, rotation of the knee can influence the FFAP. However, as we performed all the lateral X-rays in neutral rotation of the knee, we consider this effect to be minimal.

Cement penetration is dependent on more factors than just the FFAP. For example, the quality and quantity of bone lavage can influence the cement penetration pressure, since retained fat and bone marrow can prevent cement from penetrating into cancellous bone, thus increasing the cement penetration pressure [22–24]. As the operation is routinely performed through a minimally invasive approach, the posterior tibial bone may not be exposed well enough to be cleaned sufficiently and consequently cement penetration might be decreased. Tibial anchorage drill holes to open bone sclerosis could affect cement penetration as shown for the femoral fixation of the Oxford UKA [25]. The cement application technique could also determine the cement penetration. For total knee arthroplasty, a significant difference could be shown between hand packing and cement gun pressurisation technique [26].

Conclusions

The central position of the FFAP for the investigated cemented UKA with single radius femoral component at 45° flexion of the knee could be confirmed. A flexion angle of <45° does not influence the position of the FFAP significantly. With flexion of more than 45°, the FFAP shifts backwards and may lead to higher CPP in the posterior region and may cause tilting of the tibial component.

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