How the distal femoral resection angle influences stresses in ceramic total knee components

INTRODUCTION:
Single fractures of a ceramic femoral component were observed during intraoperative impaction of the implant. Our first suspicion of a significant risk factor was the velocity of the impaction as well as the weight of the impaction hammer. Related dynamic finite-element-analyses showed that stresses developed during impaction are higher in ceramic than in cobalt-chromium components, but critical stress limits were not reached [1]. The second risk factor, i.e. the resection geometry of the distal femur, was analyzed in the present study. The hypotheses was that by deflection of the oscillating saw blade from the guided direction (Figure 1), the increasing femoral resection angle might cause a bending of the total knee component during implantation. Thereby, high stresses in the ceramic material may occur. The objective of the present study was to identify the influence of the femoral resection angle on implant stress by means of finite-element-analyses.

METHODS:
We developed a finite-element-model of the distal femur including a contact formulation which allowed pushing the femoral component onto the resected femur. For clarifying its influence, the distal femoral resection angle was varied prior to virtual implantation. The opening angle of the ceramic femoral component amounted 9.0°. The distal femoral resection angle was increased stepwise in the model. Thereby, different anterior and posterior deflection angles from 0.5° to 3° were considered. In the worst case, anterior and posterior deflection both amounted 3°, resulting in a total femoral resection angle of 15°. The virtual resection was conducted using Boolean subtraction from the bone in ABAQUS/CAE V.6.10 (Dassault Systèmes Simulia Corp. 2010, Providence, RI, USA). The implant and the distal femur were meshed with tetrahedral elements with quadratic interpolation, modified for optimized contact (ABAQUS element type C3D10M). For cortical representation, a face consisting of shell elements (ABAQUS element type STRI65) with an overall thickness of 1.0 mm was created at all bone surfaces outside the resection areas. Material properties of distal femoral bone samples tested under compression were assigned to trabecular bone [2]. The shell elements representing cortical bone were assigned a Young’s modulus of 17 GPa [3]. Valid material data of the composite ceramic implant were taken from a previous study [1]. Initially, the implant was placed 6 mm apart from the bone. During analysis, the implant was pushed along the femoral axis onto the bone stock, reaching an exact-fit position on the distal femur. For experimental validation, a wedge load was applied at the ceramic component using a universal testing machine while implant strains were measured using strain gauges (HBM, Darmstadt, Germany).

RESULTS:
Since ceramics is a material with nearly no plasticity, the linear-elastic behaviour was evaluated using the maximum principal stress. Initially, the stress distribution was visualized by color plots, showing the areas which are at risk for fracture. Subsequently, a node path A was set in order to evaluate the maximum principal stresses along a true distance of the major stressed area. Node path A starts laterally at the proximal bearing surface, runs up to the distal surface, crosses the lateral condyle and ends at the U-shaped gap where the posterior cruciate ligament inserts. By plotting the maximum principal stresses along this path, it was shown that the critical stress limit was reached already when the femoral resection angle amounted 13°. That means anterior and posterior saw blade deflection amounted each 2°, each adding up to the original opening angle of 9° of the femoral component. The critical stress limit was set from literature values, which describe a range of 1,150 MPa up to 1,400 MPa, examined by four-point bending tests. Experimental validation showed good agreement of principal strains.

DISCUSSION:
In order to maintain high quality of total joint arthroplasty, it is necessary to identify risk factors for adverse events. Using numerical simulation, areas comprising high stresses under load can be identified and solutions in terms of surgical technique, implant positioning and implant design can be proposed. The presented finite-element calculations show that significantly high stresses are developed in the ceramic femoral component when the distal femoral resection angle amounts 13° or more, which is at least four degrees more than the opening angle of the implant. In conclusion, when implanting ceramic femoral components in total knee arthroplasty, the distal femoral resection angle must be prepared very precisely.

SIGNIFICANCE:
The implant manufacturer reacted by increasing surgical accuracy through an additional resection template. Moreover, the impaction of the femoral component during cementing was recommended only by hand. Since then, no further intraoperative fractures have been clinically observed.

REFERENCES: