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Dynamic in vitro measurement of posterior cruciate ligament load and tibiofemoral stress after TKA in dependence on tibiofemoral slope

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Abstract

Background. To prevent excessive tension on the posterior cruciate ligament, some knee prosthesis-systems offer the option of creating a posterior tibiofemoral slope of the tibial component. The objective of this study was to investigate the effect of the amount of tibiofemoral slope on the posterior cruciate ligament load and tibiofemoral contact stress after total knee arthroplasty under isokinetic in vitro conditions.

Methods. Twelve fresh frozen knee specimens were tested in a knee simulator. After implantation of the Interax I.S.A.® knee prosthesis-system with a mobile bearing inlay, a bow shaped load transducer was fixed in the medial fibres of the posterior cruciate ligament. A pressure sensitive film was fixed on the femoral inlay surface. The test cycle simulated an isokinetic extension cycle from 120° of flexion to full extension. First, posterior cruciate ligament load and tibiofemoral peak contact stress were measured with the tibial component implanted with a neutral tibial slope and then with 10° posterior slope.

Findings. After implantation of the tibial component without tibial slope, posterior cruciate ligament load reached a maximum load of 29.5 N (SD 17.1 N) at 97.8° knee flexion. Tibiofemoral contact stress on the medial compartment reached a maximum of 11.9 MPa (SD 2.4 MPa) on the medial compartment and 15.0 MPa (SD 6.1 MPa) on the lateral compartment. With a tibial slope of 10°, posterior cruciate ligament load reached a maximum of 14.5 N (SD 4.9 N, $P = 0.04$) at 100.5° knee flexion and tibiofemoral stress increased to a maximum of 13.3 MPa (SD 4.7 MPa, $P = 0.38$) medial and 17.4 MPa (SD 8.2 MPa, $P = 0.22$) lateral in knee extension.

Interpretation. Maximum posterior cruciate ligament load was observed at high knee flexion angles, decreasing to full extension. The implantation of the tibial base plate with 10° dorsal slope reduced posterior cruciate ligament load significantly in knee flexion above 50° and slightly increased tibiofemoral contact stress in knee extension. Therefore a posterior tibial slope prevents an excessive load on the posterior cruciate ligament while having little effect on tibiofemoral stress at high knee flexion angles.

Keywords: Knee prosthesis; Simulation; Mobile bearing; Tibial slope; Ligament load; Posterior cruciate ligament

1. Introduction

During the majority of total knee arthroplasty (TKA) implantations, it is necessary to sacrifice the anterior cruciate ligament (ACL) (Chiu et al., 2002; Lewandowski et al., 1997; Conditt et al., 2000). With this resection and the implantation of the prosthesis, the tension of the retained posterior cruciate ligament (PCL) may be increased particularly in flexion and increases the tibiofemoral stress on the polyethylene inlay due to the presence of abnormal knee kinematics and imbalances of the retained soft tissue (Chiu et al., 2002; Dennis et al., 1998; Lewandowski et al., 1997). To prevent this excessive PCL tension at high knee flexion,

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some knee prosthesis systems offer the option of creating a posterior tibiofemoral slope of the tibial component (Giffin et al., 2004; Singerman et al., 1996). In addition, in the absence of the ACL the kinematics of the tibiofemoral contact point were reversed (Stukenborg-Colsman et al., 2002b; Draganich et al., 1987). The resulting anterior displacement of the tibiofemoral contact region reduces the quadriceps extension moment (Dennis, 1998; Draganich et al., 1987). Giffin et al. (2004) described an anterior shift of the tibia during increasing the tibial slope, causing a potential posterior translation of the tibiofemoral contact point. This should lead to an improved quadriceps extension moment and higher flexion angles of the knee (Andriacchi et al., 1982; Dennis, 1998). Therefore Dorr and Boiardo (1986) recommended a 5–10° posterior tibial slope. Previous studies showed a variability of up to ±3° while cutting a planned tibial slope, which could cause an additional amount of posterior slope (Bellemans et al., 2005; Lindstrand et al., 1982; Stockl et al., 2004).

Several studies reported measurement of ligament load in the PCL. Ogata et al. (1988) used Hall-effect transducers measuring maximum load in the PCL at knee flexion above 90°, decreasing with further extension. Wascher et al. (1993) used a force transducer to measure directly the resultant PCL force and reported that the force increased gradually from 30° to 90° of knee flexion. Contact stress analysis, using pressure-sensitive Tekscan®-films (Tekscan Inc., Boston, USA), can provide a reproducible experimental technique for comparing the contact stresses of various prostheses under dynamic conditions with physiologic loads (DeMarco et al., 2000; Stukenborg-Colsman et al., 2002a). Up to now these studies have investigated the reduced stress distribution on mobile bearing inlays with high conformed inlay surfaces compared to fixed bearing inlays without changing the tibial slope (Stukenborg-Colsman et al., 2002a), which correlates to quasi-static stress measurements with Fuji®-film (Fuji Photo Film Co., Tokyo, Japan) (Szivek et al., 1995).

The objective of this study was to investigate the effect of the amount of tibiofemoral slope on maximum and minimum PCL load and tibiofemoral peak contact stress after TKA under isokinetic in vitro conditions. We hypothesized that maximum PCL load decreases, especially in knee flexion, with higher posterior tibial slope accompanied by a decreasing or not significant change of maximum tibiofemoral stress.

2. Methods

Twelve fresh frozen knee specimen were tested in an isokinetic extension test in an in vitro simulation, initially published by Stukenborg-Colsman et al. (2002a) and Ostermeier et al. (2004). The Interax I.S.A.® (Stryker/Howmedica®, Limerick, Ireland) was implanted into seven fresh frozen left knee cadaver (mean age 63, range 52–78 years). The knees were transected about 300 mm proximal and distal to the knee joint. The skin and subcutaneous tissues were removed, preserving the muscles, articular capsule, ligaments and tendons. The ACL was removed and the PCL preserved. The femoral and tibial components were normally aligned as recommended by the manufacturer's guidelines in neutral position to the mechanical axis with no tibial slope. In the sagittal plane the shape of the femoral component provides a constant radius from 0° to approximately 90° of knee flexion, reducing to higher degrees of flexion. The femoral component articulates with a mobile, anterior/posterior sliding inlay.

After implantation of the knee prosthesis-system with a 6 mm mobile bearing inlay, a bow shaped custom made force transducer (FoWe MHH, Hannover, Germany) was fixed in the medial fibres of the PCL, with care being taken to minimally disrupt the soft tissues of the knee during insertion. The force transducer was fixed on one of its edges with a single suture to the ligaments fibres (Fig. 1).

A pressure sensitive film (*K*-scan sensor: Tekscan® Inc.) was fixed on the femoral inlay surface (Fig. 1). This electric/resistive pressure film senses the location, timing and pressure distribution of contact stresses ranging in a magnitude from 0.1 to 69 MPa. The sensor has two separate sensing areas measuring 33×22 mm and 0.1 mm thick. The sensors consist of 26×22 rows and columns with intersection points that form the sensing location. Each sensing area (medial and lateral compartments) therefore comprises 572 individual sensors or "sensels". The sensors were glued to the medial and lateral compartments of the polyethylene inlay so that about 95% of the inlay surface was covered. Tibiofemoral peak contact stress was thus measured dynamically with 10 Hz in both the medial and lateral compartments of the prosthesis. The pressure films were preconditioned by repeated loading and unloading

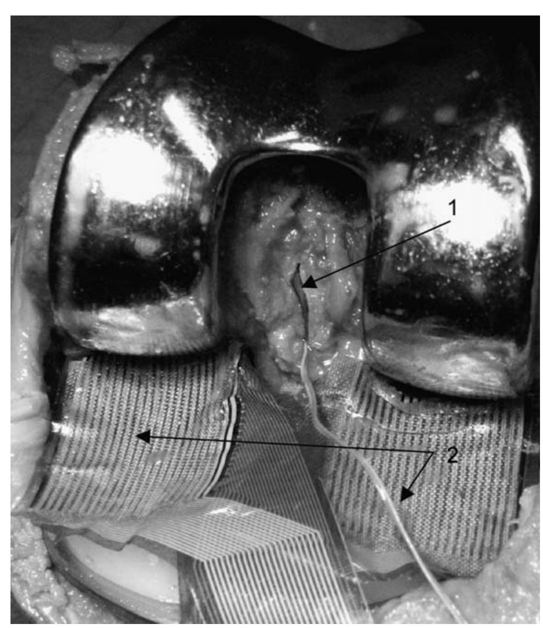

Fig. 1. Intraoperative view of the knee joint after TKA with the implanted force transducer (1) and the attached pressure sensitive film (2, *K*-scan®, Tekscan, Boston, USA).