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Tibiofemoral contact mechanics with a femoral resurfacing prosthesis and a non-functional meniscus

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ABSTRACT

Background: Increased contact stress with a femoral resurfacing prosthesis implanted in the medial femoral condyle and a non-functional meniscus is of concern for potential deleterious effects on tibiofemoral contact mechanics.
Methods: Peak contact pressures were determined in seven fresh frozen human cadaveric specimens using a pressure sensitive sensor placed in the medial compartment above the menisci. A knee simulator was used to test each knee in static stance positions (5°/15°/30°/45°) and through 10 dynamic knee flexion cycles (5–45°) with single body weight ground reaction force which was adjusted to the living body weight of the cadaver donor. All specimens were tested in three different conditions: untreated knee (A); flush implantation of a 20 mm resurfacing prosthesis (HemiCAP®) in the weight bearing area of the medial femoral condyle (B); complete radial tear at the posterior horn of the medial meniscus with the femoral resurfacing device in place (C).
Findings: On average, flush device implantation resulted in no statistically significant differences when compared to the untreated normal knee. The meniscal tear resulted in a significant increase of the mean maximum peak contact pressures by 63%, 57%, and 57% (all $P \leqslant 0.05$) at 15°, 30° and 45° static stance positions and 78% ($P \leqslant 0.05$) through the dynamic knee flexion cycle. No significant different maximum peak contact pressures were observed at 5° stance position.
Interpretation: Although the condition of a meniscal tear without the resurfacing device could not be compared, possible effects of reduced meniscal tissue and biomechanical integrity of the meniscus must be considered in an *in vivo* application.

1. Introduction

Full thickness articular cartilage defects are frequently diagnosed and often associated with substantial morbidity and functional limitation (Curl et al., 1997). Hjelle et al. (2002) diagnosed focal chondral or osteochondral defects (of any type) in 19% of the patients evaluating one thousand consecutive knee arthroscopies. Location of the cartilage defects were predominantly on the medial femoral condyle and concomitant meniscal injury was found in 42% of these patients. Increased incidence of osteoarthritis is demonstrated with the presence of a significant chondral or osteochondral defect and/or with loss of meniscus tissue by partial or total meniscectomy in numerous studies (Fairbank, 1948; Hede et al., 1992; Higuchi et al., 2000; Linden, 1977; Maletius and Messner, 1996; Rangger et al., 1997; Shelbourne et al., 2003).

The patient over the age of 40 years with a focal full thickness chondral or osteochondral defect reflects a serious problem for the orthopedic surgeon. Conservative treatment at best ameliorates the symptoms. Biological repair techniques, such as autologeous chondrocyte transplantation, osteochondral transplantation (OATS, Mosaicplasty) and marrow stimulation techniques have shown promising results in younger patients (Hangody and Fules, 2003; Mithoefer et al., 2005; Nehrer et al., 2006; Peterson et al., 2002) but appear to be increasingly ineffective with increasing age (Kreuz et al., 2006; Mithoefer et al., 2005). Unicompartimental or total knee arthroplasty represent procedures of final resort prompting the likelihood of revision surgery for the middle aged patient with associated morbidity during the patient's lifetime.

A novel metallic resurfacing prosthesis (HemiCAP®, Arthrosurface Inc., Franklin, MA, USA) was developed as an interim or alternative treatment strategy in patients when only one compartment is affected by posttraumatic, degenerative disease or necrosis associated with large unstable articular defects with significant subchondral bone exposure. However, effects of a metallic implant

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articulating with intact opposing tibial articular cartilage and meniscus remain largely unanswered to date. In a previous biomechanical study, flush implantation did not appear to be a biomechanical disadvantage, whereas elevated implantation of the device has shown significantly increased tibiofemoral peak contact pressures compared to the untreated condition in human cadaver knees with intact chondral surfaces and menisci (Becher et al., 2008).

The menisci of the knee aid in load bearing (Kurosawa et al., 1980; Seedhom et al., 1974) and joint stability (Sullivan et al., 1984). Load transfer characteristics are altered in injured menisci or after total or partial meniscectomy. An *in vitro* study in human cadaver knee specimens has demonstrated increased peak contact pressures proportionally to the amount of meniscus removed (Lee et al., 2006). Increased peak contact pressures up to 136% was shown after total medial meniscectomy (Lee et al., 2006). No information exists, however, if loss of meniscus integrity and meniscus function might lead to deleterious effects to the articular cartilage of the tibial plateau with the metallic device implanted in the weight bearing area of the medial femoral condyle.

This *in vitro* study aims to determine the effect of a complete radial tear on peak contact pressure in the tibiofemoral joint with the resurfacing prosthesis implanted in the medial femoral condyle.

2. Materials and methods

A total of seven fresh frozen knee cadaver specimens (3 pairs, 1 single) were used for data collection in this study. The specimens were obtained from donors, who consented in writing during their lifetime to the use of their body for research and education. The average age of the seven male specimen was 69 years (range: 61–78) with an average weight of 72 kg (range: 61–85 kg). Specimens were selected after inspection of the medial compartment according to the following criteria: intact tibiofemoral cartilage, intact meniscus, and intact collateral and cruciate ligaments. A total of 24 knees were screened resulting in seven knees being appropriate according to the inclusion criteria.

A specially designed knee simulator was used for this study (Fig. 1) (von Skrbensky and Huber, 2006). Similar to in vivo conditions, the main system composed of artificial muscle, force transducer sensor, the joint angle detection and the ground reacting force form a closed loop. The ground reaction force is adjustable according to the donor's weight. The knee simulator consists of a loading frame (MTS™ 858 Eden Prairie, St. Paul, USA) with a long stroke main actuator driven by a hydraulic pump unit (MTS 505.11 silent flow) to simulate body weight and the vertical hip displacement in the mechanical axis of the lower limb. Ankle joint simulation is performed with a hinge joint with one free motion axis. The possible rotation during the movement occurs in the artificial hip joint as if standing with fixed shoe contact. A load transducer is fixed between the mounting plate and ankle joint to detect the vertical ground reacting force (U3 load cell, Hottinger-Baldwin™, Darmstadt, Germany). Two smaller actuators apply loads which simulate the quadriceps force. The tendons of the quadriceps muscle are attached to customized curved cryoclamps which avoid patella tilting. A cooling liquid is flowing through the cryoclamps (Haake Synth 60, Karlsruhe, Germany) at a steady temperature of minus 24° C (248 K) (Haake GH, temperature controller D8, Karlsruhe, Germany). These cryoclamps are connected to a waterproof force transducer (SSM-AJ 500, Interface™, Scottsdale, Arizona, USA) and connected to an artificial muscle (Fluidic muscle MAS, Festo®, Esslingen, Germany). The MAS consists of an inner chloroprene tube covered with an aramid fibre shell in a helical mesh. Pressurization of the chloroprene tube results in a longitudinal shortening of the device of up to 25% by increasing the diameter. The mathematical model shows, that the properties of this fluidic muscle is comparable with a skeletal muscle (Tondu and Lopez, 2000). Two MAS40 (40 mm diameter) fluidic muscles are simulating the quadriceps muscle. Two proportional valves (MPPS ¼ 6-010, Festo, Esslingen, Germany) control the air flow to the muscles, provided by a 0.6 MPa medical air pressure line. The proportional valve is integrated in a closed loop with the force transducers. The amplified signal from the ground reaction force transducer is the reference input for the MPT Controller (MTS Multi Purpose Test Star™, Eden Prairie, St. Paul, MN, USA) which calcu-

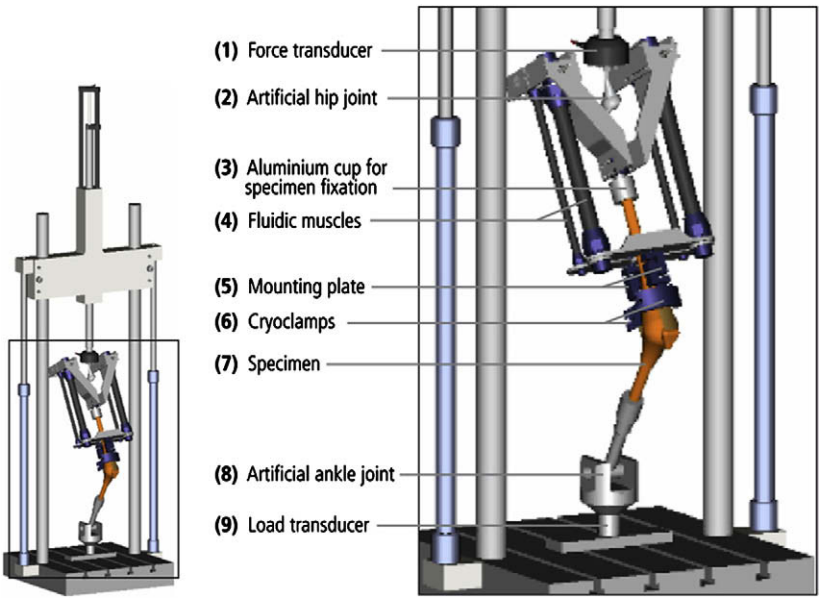

Fig. 1. Schematic presentation of the knee simulator. The hydraulic actuator is displacement controlled and connected with a force transducer (1). The default signal is equal to the hip joint (2) movement. The specimen (7) is mounted in aluminium cups (3) using cerro bend alloy. Fluidic muscles (4) simulate the quadriceps and hamstrings. A mounting plate connects the muscle configuration with the force transducer (5) and is connected to the tendons of specimen by two cryoclamps (6). A load transducer (9) is fixed between the mounting plate and ankle joint (8) to detect the vertical ground reacting force.