Clinical Biomechanics 32 (2016) 28–33

Contents lists available at ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

Deformation pattern and load transfer of an uncemented femoral stem with modular necks. An experimental study in human cadaver femurs

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ARTICLE INFO

Article history:
Received 11 March 2015
Accepted 6 January 2016

Keywords:
Total hip arthroplasty
Cortical strain
Deformation pattern
Load transfer
In vitro study
Modular necks
Neck version
Femoral offset

ABSTRACT

Background: Modular necks in hip arthroplasty allow variations in neck-shaft angles, neck version and neck lengths and have been introduced to improve accuracy when reconstructing the anatomy and hip joint biomechanics. Periprosthetic bone resorption may be a consequence of stress shielding in the proximal femur after implantation of a femoral stem. The purpose of this study was to investigate the deformation pattern and load transfer of an uncemented femoral stem coupled to different modular necks in human cadaver femurs.
Methods: A cementless femoral stem was implanted in twelve human cadaver femurs and tested in a hip simulator corresponding to single leg stance and stair climbing activity with patient-specific loading. The stems were tested with four different modular necks; long, short, retro and varus. The long neck was used as reference in statistical comparisons, as it can be considered the "standard" neck. The deformation of bone during loading was measured by strain gauge rosettes at three levels of the proximal femur on the medial, lateral and anterior side.
Findings: The cortical strains were overall reduced on the medial and lateral side of femur, for all implants tested, and in both loading conditions compared to the unoperated femur. Although there were statistical significant differences between the necks, the results did not show a consistent pattern considering which neck retained or lost most strain. In general the differences were small, with the highest significant difference between the necks of 3.23 percentage points.
Interpretation: The small differences of strain between the modular necks tested in this study are not expected to influence bone remodeling in the proximal femur.

1. Introduction

Modularity is a well-known concept in revision arthroplasty, and the use of modular components in primary total hip arthroplasty (THA) has increased in recent years (Australian Orthopaedic Association National Joint Replacement Registry, 2014; National Joint Registry for England and Wales, 2014, The New Zealand Joint Registry, 2013)

Reconstruction of hip joint geometry is one of the goals in arthroplasty, but can be challenging, especially in cases of hip joint deformity. Leg length discrepancy or inadequate femoral offset, may lead to poorer clinical outcome for the patients (Kotwal et al., 2009; Lecerf et al., 2009).

The concept of modular necks allows for variations in neck-shaft angles, neck version and neck lengths in THA and can improve the anatomical relation and hip joint biomechanics (Krishnan et al., 2013).

There is limited long-term documentation on modular necks in primary THAs. There are reports of good mid-term results (Matsushita et al., 2010; Omlor et al., 2010), however, according to the Australian Joint Registry the revision rate of THA with exchangeable femoral necks is twice the revision rate of conventional THA 8 years after surgery, implant loosening being one of the primary reasons (Australian Orthopaedic Association National Joint Replacement Registry, 2014). In addition several case series and case reports have shed light over problems with modular necks, due to fretting, corrosion and pseudotumor formation (Dangles and Altstetter, 2010; Gill et al., 2012; Skendzel et al., 2011; Sotereanos et al., 2013; Viceconti et al., 1996, 1997) Pastides et al., 2013.

The human bone remodeling is a complex process, where the mechanical stimulus of the bone cells is an important factor (Engh et al., 2003; Glassman et al., 2006). The clinical observation of bone remodeling, usually referred to as Wolff's law, is that bone density increases when load increases, and decreases when load decreases. Periprosthetic

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http://dx.doi.org/10.1016/j.clinbiomech.2016.01.001
0268-0033/

bone resorption in the proximal femur is a well-known phenomenon after THA, and is commonly explained by adaptive bone remodeling due to stress-bypassing in the proximal femur. The phenomena is termed stress shielding, referring to that after implanting a stiffer femoral stem, the proximal femur is shielded or protected from loading (Glassman et al., 2006).

Stress shielding seems to be influenced by the fixation techniques, material properties and stem design, as well as patient-related factors. An alteration of the biomechanical environment and hence adaptive bone remodeling may lead to compromised support of the femoral stem and subsequent loosening of the prosthesis and complications during revision surgery.

There are a few experimental studies of deformation patterns and modular femoral necks in synthetic bones. These studies have used different angle, version and length in modular necks, looking at the pattern of load transfer in proximal synthetic femur after insertion of the implants (Politis et al., 2013; Umeda et al., 2003).

Human cadaver femurs have some advantages over synthetic bones in experimental set-ups, as they provide an expected natural variation in both geometry and material and are therefore more clinically relevant. However, they are not easy to obtain and must be handled with special care. To our knowledge there are no studies on modular necks recording cortical deformation in human cadaver femurs.

The purpose of this study was to evaluate the load transfer expressed by the cortical deformation pattern of an uncemented femoral stem with four different modular necks varying neck-version, neck-length and neck-shaft angle in human cadaver femurs.

2. Material and methods

2.1. Implant system

Four modular titanium necks with a 12/14 taper (Profemur® Modular Necks, Wright Medical Technology Inc, Arlington, TN USA 38002) were evaluated: 1. Straight long (PHAO 1204), 2. Straight short (PHAO 1202), 3. Retroverted short 15° (PHAO 1262) and 4. Varus short 15° (PHAO 1242) modular component (Fig. 1). The necks were connected into the femoral stem pocket through the oval end. A 28 mm femoral head was used for articulation. Cementless titanium alloy collarless stems fully coated with hydroxyapatite (HA) (Profemur® PRGLKITD Gladiator, Wright Medical Technology Inc, Arlington, TN USA 38002) were implanted, randomly allocated to right or left side. The implantations were performed by the same experienced orthopedic surgeon and according to the manufacturer's procedure (Wright Medical Technology, 2013).

Fig. 1. Profemur® modular necks: varus short 15°, retroversion short 15°, straight short and straight long (reference neck) in front view.

2.3. Human cadaver femurs

Caucasian human cadaver femurs were collected from deceased patients that underwent medical post-mortem examinations within 24 h. Consents from the relatives were obtained before interfering. The Regional Committee for Medical Research Ethics, Western Norway, approved the project. Twelve human femurs were tested, mean donor age was 58 years (range 43–70 years), nine males and three females. The same set of subjects was also used in a previous study (Enoksen et al., 2014).

The femurs were handled and prepared according to an earlier described and well documented procedure (Aamodt et al., 2001).

Two projections X-ray were used to estimate the size of the prosthesis and to exclude any skeletal pathology. Dual-energy X-ray absorptiometry (Lunar Prodigy Advance, General Electric Healthcare, California, USA) were obtained to diagnose any osteoporotic femurs. Bones with T-scores in the proximal femur below −2.5 were classified as osteoporotic and excluded.

The inclusion criteria of femurs were age ≤70 years in accordance with clinical practice at our department for uncemented stems. A body mass index ranging from 18 to 30 representing normal weight and to comply with the hip simulator, designed for normal size femurs and normal loading. Exclusion criteria were no previous fracture in the femur and no current or previous malignancy in the femur. A collection of twenty-one pairs of femurs was available. Five subjects failed during testing, three subjects were excluded due to osteoporosis and one pair was destroyed during preparation. Single femurs from twelve donors were therefore eligible for testing.

Before testing, the frontal plane of femur was defined by placing the femur on a horizontal surface resting on the posterior condyles and the greater trochanter. The anteversion of the femoral neck was measured and recorded for later orientation of the femur in the frontal and sagittal planes. The condyles were then resected and the femur was fixed into a steel cylinder with acrylic bone cement (Meliodent, Heraeus Kulzer GmbH, Hanau, Germany), aligning the center axis of femur with the center axis of the cylinder. The distance from the tip of the greater trochanter to the top of the cylinder was 25 cm for all specimens. Hip abductor muscles were simulated with a 40 mm polyamide strap attached to the greater trochanter using methacrylate glue (X 60, HBM GmbH, Darmstadt, Germany) and 6 cortical screws (Fig. 2).

2.4. Hip simulator

The hip simulator used in this study is well documented (Aamodt et al., 2001; Enoksen et al., 2014; Ostbyhaug et al., 2009; Wik et al., 2011). The operated femurs were mounted into a hip jig and loaded in a servohydraulic testing machine (MTS 858 MiniBionix II, MTS System Corporation, Eden Prairie, Minnesota, USA) (Fig. 2). The femur could rotate freely around its longitudinal axis and tilt freely in the medial/lateral plane, to avoid unphysiological bending moments.

The femur was tilted 12° into valgus, corresponding to physiological inclination during single leg stance (McLeish and Charnley, 1970). The femoral angle was kept the same for every test situation by adjusting the lower end of the cylinder, holding the femur. An acetabular cup with an inclination of 45° and 0° anteversion was used in this test set up. A trochanter strap was fixed to the lever arm to simulate the abductor muscles. The attachment of the strap to the lever arm was adjusted to achieve an angle of 15° to the load axis (McLeish and Charnley, 1970) in every test situation.

Single leg stance and stair climbing activities were tested. The femurs were loaded in the vertical axis proportionally to their individual