Clinical Biomechanics 28 (2013) 415–422

Contents lists available at SciVerse ScienceDirect

Clinical Biomechanics

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

Patterns of stress distribution at the proximal femur after implantation of a modular neck prosthesis. A biomechanical study

Angelos N. Politis [a,b,*], George K. Siogkas [b,c], Ioannis D. Gelalis [b], Theodore A. Xenakis [b]

[a] *Department of Orthopaedic Surgery, Jewish General Hospital, McGill University, Montreal, Canada*
[b] *Laboratory of Biomechanics, University of Ioannina, School of Medicine, Ioannina, Greece*
[c] *Department of Electrical and Computer Engineering, University of Patras, Greece*

ARTICLE INFO

Article history:
Received 30 July 2012
Accepted 5 February 2013

Keywords:
Strain
Modular
Neck
Femur
Arthroplasty

ABSTRACT

Background: Modular total hip arthroplasty incorporating a double taper design is an evolution offering potential advantages compared to single head–neck taper or monolithic designs. Changes in femoral offset, neck length or femoral anteversion are expected to alter the strain distribution.

Methods: We therefore analyzed the strain patterns after usage of all types of necks of a modular neck prosthesis, implanted in composite femurs.

Findings: The load distribution presented a repeatable pattern. Anteverted neck combinations resulted in higher stress at the anterior surface, whereas the retroverted ones at the posterior (e.g. at the middle frontal site, stress is 13.63% higher when we shifted from the long neutral neck to the long 15° anteverted neck and at the middle back site 19.73% higher when we shifted from the long neutral to the long 15° retroverted neck). Compressive stress was larger at the calcar region and exacerbated by the use of the varus neck (e.g. at the frontal 1 site stress increased by 44.01% when we used the long 8° varus neck in comparison to the long neutral neck). Anteverted neck combinations resulted in higher strain at the anterior cortex around the tip of the prosthesis. Short necks exhibited lower stress at the femoral shaft and higher at the trans-trochanteric area.

Interpretation: Anteverted neck combinations could be more prone to anterior thigh pain. Because of the possible risk of adaptive hypertrophy and early mechanical failure due to increased stress, the surgeon should be cautious when using necks with combined characteristics or short necks.

1. Introduction

Modular total hip arthroplasty (THA) incorporating a double taper design is an innovation offering potential advantages compared to single head–neck taper or monolithic designs (Dunbar, 2010). Those include the adjustment of leg length and offset via the head–neck taper, femoral anteversion via the neck–stem taper, easier revision when there is no need to revise a well-fixed femoral stem and optimal restoration of soft tissue tension and patient biomechanics (Dunbar, 2010). The use of modular necks has thus increased in the recent years and authors reported good mid- and long-term clinical outcomes (Benazzo et al., 2010; Sakai et al., 2010).

Adjusting femoral offset, leg length and orientation of the components are of crucial importance. Offset correlates to abductor muscle function, wear and impingement (Dastane et al., 2011). On the other hand, over-lengthening of the limb can be a problem (Konyves and Bannister, 2005), whereas failure to comply with the recommendations for acetabular inclination/anteversion and femoral anteversion may lead to edge loading and prosthetic impingement, which can cause dislocation, mechanical loosening, wear or breakage of the polyethylene liner, metallosis or metal ion release in metal-on-metal bearings, and squeaking or breakage of ceramic-on-ceramic bearings (De Haan et al., 2008; Miki and Sugano, 2011).

Are changes in femoral offset, neck length or femoral anteversion expected to alter the strain distribution at the femur? The aim of this biomechanical study is to analyze and compare the strain patterns at the proximal femur after usage of all types of necks of a commercially available modular neck stem prosthesis and possibly connect the results with the clinical praxis.

2. Methods

In this study a set of cementless modular PROFEMUR-E® Total Hip Replacement System (Wright Medical Technology Inc., Arlington, TN, USA) was used. The aforementioned stem is a modular prosthesis manufactured from Ti6Al4V and has a 500 μm thick coating of pure titanium plasma spray. The surgeon may choose between six interchangeable necks available in two lengths and a total of 22 combinations can be used. We used custom-made, commercially available, medium left, fourth generation, medium composite femoral models

---

* Corresponding author at: Department of Orthopaedic Surgery, Jewish General Hospital, McGill University, 447, Ave Prince Albert, Apt. 4, Westmount, Montreal, Canada H3YP6.
E-mail address: medpolitis@yahoo.co.uk (A.N. Politis).

0268-0033/$ – see front matter. Crown Copyright © 2013 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.clinbiomech.2013.02.004

(model # 3403-99, Sawbones, Pacific Research Laboratories, Vashon Island, WA, USA). The bones were already osteotomized and specifically machined for use with a size 3 Profemur-E stem. A custom-made fixture designed to reproduce loading conditions during the single-leg stance phase of walking, as described by McLeish and Charnley (1970), was attached to the load cell of a computer-controlled hydraulic testing machine (MTS 858 Mini Bionix, MTS Systems Corp, Eden Prairie, MN, USA). The femur was tilted into 12° of valgus and was positioned neutral on the sagittal plane. Hip abductors were simulated by a small chain attached to a custom-made base that was fixed to the lateral aspect of the greater trochanter. The abductor force simulation applied the load at an angle of abduction 15° to the sagittal plane (Finlay et al., 1989; McLeish and Charnley, 1970). The distal end of the femur was embedded in a steel pot with radiopaque bone cement. A modified universal ball joint was mounted between the distal construct and the base of the machine (Fig. 1).

The circumference of the femoral model was divided into 3 parts and strain gages were fixed along the lateral, medial-anterior and medial-posterior surface of the femur at positions 60° apart. Three 350-Ohm tri-axial rosette strain gages (KYOWA, KFG-2-350-D17-11, Kyowa Electronic Instrument, Tokyo, Japan) were bonded on the transtrochanteric surface, where a more complex strain pattern was expected. One rosette was made up of three strain gages mounted at 60° angles. The median of the peak-to-peak value of the sinusoidal strain over time was computed for each of the three gages. Uni-axial 350-Ohm strain gages (KYOWA, KFG-2-350-C1-11, Kyowa Electronic Instrument, Tokyo, Japan) were used along the shaft of the femur, where the strain pattern was expected to be simpler. The uni-axial strain gages were distributed at three horizontal levels at 48, 96, and 144 mm below the level of the lesser trochanter, so that the middle gages were around the tip of the stem. The leads of the gages were connected to a Wheatstone bridge configuration (Kyowa SS-24R Switching and Balancing Box, Kyowa Electronic Instrument, Tokyo, Japan). The gage outputs were transferred to a signal amplifier module and consequently to an (MTS TestStar II® data acquisition system, MTS Systems Corp, Eden Prairie, MN, USA).

Load cycles were programmed to simulate single-leg stance of a normal-weight subject. Applying a vertical force five sixths of the body weight, with the weight of the lower extremity subtracted, would yield a physiological resultant hip joint force in the hip simulator (Wik et al., 2011). Thus, an axial load of 600 N was applied to simulate the single-leg stance of a subject weighing 70 kg. A 3-step testing sequence was used as follows: 1. Ramp-up to −300 N (rate 100 N/s). 2. Sinusoidal axial loading between −100 and −600 N applied at a frequency of 1 Hz for 200 cycles. 3. Ramp-down to −50 N (rate 500 N/s). The material testing system operated under force control. Load cell limit was set at −750 N. Strain values were recorded for 200 full cycles. Tests were repeated three times for every composite bone to obtain the average strain for each gage. The set of the three tests was repeated on three different composite femurs. The position of the strain gages was checked constant with the use of a phantom femoral model. All conditions were tested on every composite bone. Prior to testing, the abductor chain was pre-tensioned until the level arm was balanced at the horizontal plane in the beginning of every load cycle. Three specimens were tested and statistics were performed on the three sets of data obtained from the three specimens. Every set of data included all neck variations and was retrieved from the same specimen.

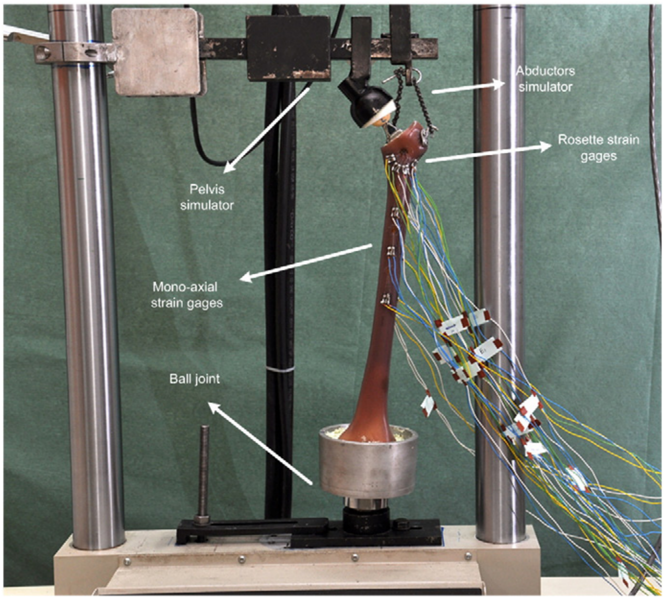

Fig. 1. Experimental set-up.

The following neck variations were tested:

- Long neutral
- Long 8° anteverted (long 8 DG A)/long 8° retroverted (long 8 DG R)
- Long 8° varus (long 8 DG VAR)/long 8° valgus (long 8 DG VAL)
- Long 15° anteverted (long 15 DG A)/long 15° retroverted (long 15 DG R)
- Long varus valgus 1 anteverted (long VAR VAL 1 A = anteverted and valgus)/long varus valgus 1 retroverted (long VAR VAL 1 R = retroverted and varus)
- Long varus valgus 2 anteverted (long VAR VAL 2 A = anteverted and varus)/long varus valgus 2 retroverted (long VAR VAL 2 R = retroverted and valgus)
- Short neutral
- Short 8° anteverted (short 8 DG A)/short 8° retroverted (short 8 DG R)
- Short 8° varus (short 8 DG VAR)/short 8° valgus (short 8 DG VAL)
- Short 15° anteverted (short 15 DG A)/short 15° retroverted (short 15 DG R)
- Short varus valgus 1 anteverted (short VAR VAL 1 A = anteverted and valgus)/short varus valgus 1 retroverted (short VAR VAL 1 R = retroverted and varus)
- Short varus valgus 2 anteverted (short VAR VAL 2 A = anteverted and varus)/short varus valgus 2 retroverted (short VAR VAL 2 R = retroverted and valgus)

One-way analysis of variance (ANOVA) of the data was performed using MatLab (The MathWorks Inc, Natick, MA, USA). Post-hoc analysis was performed using the Tukey–Kramer test. A P value <0.05 was considered statistically significant.

3. Results

3.1. Long neutral neck vs long 8° anteverted neck (long 8 DG A) vs long 8° retroverted neck (long 8 DG R) (Fig. 2, Table 1)

Strain measurement of the uni-axial strain gages revealed that longitudinal deformation was compressive on the medial side of the femur and tensile on the lateral. Strain analysis from the rosette gages on the anterior surface of the trans-trochanteric area revealed that gages 1 and 2 (the gage parallel to the longitudinal axis of the femur and the gage 60° deviated towards the medial side) showed compressive signal, while gage 3 (the gage 60° deviated towards the lateral side) showed tensile signal. Strain analysis from the rosette gages on the posterior surface of the trans-trochanteric area revealed that strain gage 1 (the gage 60° deviated towards the lateral side) showed tensile signal, while strain gages 2 and 3 (the gage parallel to the longitudinal axis of the femur and the gage 60° deviated towards the medial side) showed compressive signal. A consistent finding was that the long 8 DG A neck “conducted” stresses towards the anterior surface of the femur, while the long 8 DG R neck towards the posterior.