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Effects of positioning and notching of resurfaced femurs on femoral neck strength: a biomechanical test

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ABSTRACT

Purpose. To assess the effects of positioning and notching of resurfaced femurs on the mechanical strength of third-generation saw bone (TGSB) femurs using an *in vitro* analogue bone model.
Methods. 30 TGSB femurs were equally divided into 6 resurfaced femur groups (intact, anatomic, varus, valgus, anatomically notched, and valgus notched) for testing the load to failure, stiffness, and total energy.
Results. Compared to the intact femurs, the load to failure in all resurfaced femurs was significantly decreased by 29 to 57%. Among the resurfaced femurs, valgus and anatomic femurs had the highest load to failure, followed by valgus notched, varus, and anatomically notched femurs. Notching weakened the construct by a further 24 to 30%.
Conclusion. To minimise the risk of femoral neck fracture, resurfaced femoral heads should be placed in an anatomic or valgus orientation, and the superior cortex of the femoral neck should remain intact.

Key words: *arthroplasty, replacement, hip; femoral neck fractures; mechanics*

INTRODUCTION

Hip resurfacing arthroplasty is an alternative to total hip arthroplasty (THA). It preserves proximal femoral bone stock and keeps the medullary canal intact to facilitate a revision THA should the hip resurfacing fail.[1] Nonetheless, periprosthetic femoral neck fractures are common complications, ensuing in 1.46% of the 2497 Birmingham hip resurfacing arthroplasties carried out in Australia between 1999 and 2004.[2] Femoral neck notching and component malalignment are risk factors, particularly varus malpositioning.[3,4] The time to fracture varies from 0 to 56 (mean, 15.4) weeks.[2,5] The biomechanical properties of the femoral neck may change over the short term (because of stress shielding) and lead to fracture.[6–8]

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Table 1
Descriptions of the 6 third-generation saw bone (TGSB) models

TGSB model	Description
Intact	No hip resurfacing
Anatomic	Placement of the resurfacing head at 127°
Varus	Placement of the resurfacing head at 117°
Valgus	Placement of the resurfacing head at 137°
Anatomically notched	Anatomic placement of a resurfacing head with a 4-mm superior cortical notch
Valgus notched	Valgus placement of a resurfacing head with a 4-mm superior cortical notch

Figure 1 A resurfaced femur is tested using a MTS 858 testing system.

We assessed the effects of hip resurfacing alignment and superior neck notching on the mechanical integrity of third-generation saw bone (TGSB) femurs using an *in vitro* analogue bone model.

MATERIALS AND METHODS

30 TGSB femurs were equally divided into 6 groups (intact, anatomic, varus, valgus, anatomically notched, and valgus notched). They were tested for the load to failure after hip resurfacing using a 48-mm Biomet ReCap (Biomet, Sydney, Australia). These femurs simulated natural cortical bone and were produced by pressure-injecting short e-glass fibre and epoxy resin around a solid rigid polyurethane foam cancellous core. Under compression, the cortex has a strength of 120 MPa and an elastic modulus of 7600 MPa (compared to 17000 MPa for bone). The cancellous core has a strength of 4.8 MPa and an elastic modulus of 104 MPa.

Standard Biomet ReCap instrumentation was used to prepare the femurs. In the anatomic group, the resurfacing head was placed at 127°. In the varus and valgus groups respectively, the entry point of the alignment guide wire was moved a fixed distance superiorly or inferiorly on the lateral femoral cortex (Table 1). The guide wire was set at the correct angle of varus and valgus to avoid neck notching during reaming. The resurfacing heads were placed at 117° and 137°, respectively. In the anatomically and valgus notched groups, a standardised 4-mm deep notch was created by a ribbon saw in the superior neck, just distal to the base of the resurfacing head (Table 1). The implants were firmly positioned, but not cemented.

Orientations and proper seating of the resurfacing heads were verified using radiography and computer tomography. The femurs were evaluated according to the International Standard (ISO 7206-8) for testing a stemmed hip prosthesis under combined bending and torsion.[9] This standard specifies a testing orientation of 9°±1° flexion and 10°±1° adduction, at which maximal loading is experienced by the femur during the normal human gait cycle.

A vertical load was applied to the superior surface of the resurfacing head and gradually increased at a displacement of 0.1 mm/s until the femoral neck fractured, using a MTS 858 servo-hydraulic testing system (Fig.1). The load applied, displacement, and load to failure (in Newtons) were measured. The stiffness was calculated as the rate of change of load applied with respect to displacement (N/mm). The total energy was calculated as the integral of the load applied with respect to the total displacement (N.mm).

Differences between groups was determined using analysis of variance. Comparison between groups was made using a least significant difference post-hoc test, with a p value of <0.05 set as significant.

RESULTS

The load to failure and the stiffness of the construct

Table 2
Results of biomechanical tests

Femoral type	**Load to failure (N)** Mean±SD	**Stiffness (N/mm)** Mean±SD	**Energy (N.mm)** Mean±SD
Intact	6149±340	2773±218	7817±622
Anatomic	3734±263	1115±221	8835±984
Varus	2847±158	1419±301	4420±890
Valgus	4374±400	1525±360	7145±1594
Anatomically notched	2628±147	1428±163	3718±1131
Valgus notched	3322±376	1376±308	5051±1042

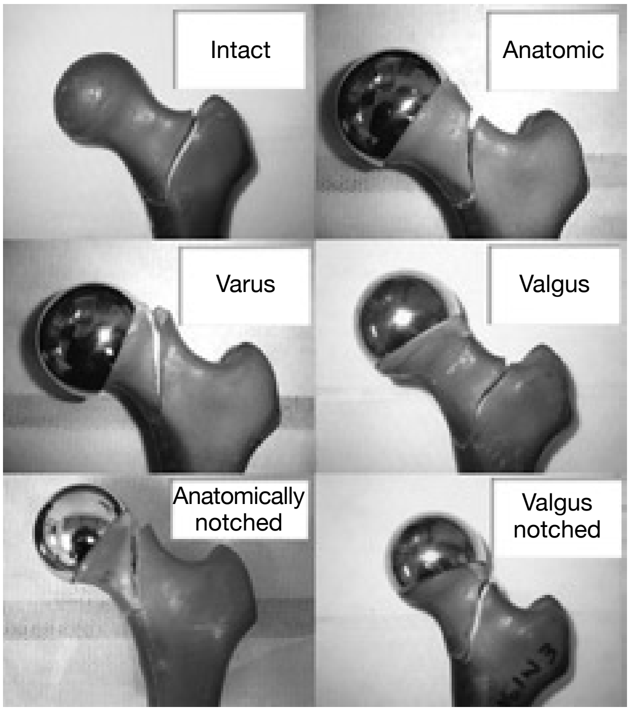

Figure 2 Fracture patterns of the 6 types of femoral heads.

was significantly reduced by 29 to 57% ($p<0.0001$) in all resurfacing groups when compared to the intact group (Table 2). Among the resurfacing groups, the valgus orientation had the highest load to failure. It decreased significantly in the remaining groups (anatomic and valgus notched, $p<0.001$; varus and anatomically notched, $p<0.0001$). Notching further decreased the load to failure of both the anatomic and valgus groups by 24 to 30%. However, the varus group was weaker than the valgus notched group ($p<0.03$). The fracture energy was higher in the anatomic than intact group but not significantly (Table 2).

In the intact, anatomic, and valgus groups, the fracture line was away from the bone-prosthesis junction and near the lateral trochanteric region of the neck, running at an oblique angle to the load path. In the varus, anatomically notched, and valgus notched groups, the fracture line started at the superior edge of the bone-prosthesis junction or at the notch and ran almost parallel to the load path (Fig. 2). The orientation of the fracture line was correlated with the energy to failure and the load to failure, with the former groups having a higher fracture energy.

DISCUSSION

In 46 fresh frozen intact femoral necks, the mean loads to failure were 9501 (range, 2544–17125) N in men and 6036 (range, 3327–9786) N in women.[10] These values were consistent with those in our intact TGSB femurs and in cadaveric resurfaced femurs (mean, 8580; range, 5524–15319) N.[11] The wide variation in human bones was likely to mask the effects of prosthetic placement on femoral neck strength. Cadaveric bones degrade biologically and lead to wide variations in their biomechanical properties, even in the same patient.[12,13] TGSB femurs were therefore a substitute for human bone, because of their uniformity, consistency, and similarity.[14] In our study, groups and results were standardised, and the low standard deviations indicated the precision of the technique. Nonetheless, in the clinical setting patients may present with valgus or varus femoral structures, which may affect femoral neck strength. The use of TGSB femurs controlled for these variations, and the effect of resurfaced head positioning alone was measured. A separate study is needed to assess the combined effect of positioning and patient anatomy.

The fracture lines in notched and un-notched TGSB femurs correlated with those for cadaveric femurs.[14] In our study, the default fracture pattern caused by vertical shear forces began quite laterally in the femoral neck. The position of the resurfacing head in the intact, anatomic, and valgus groups did not affect the strength of the lateral trochanteric region or predispose the femoral neck to fracture. In the varus, anatomically notched, and valgus notched groups, a stress riser caused a fracture in the superior neck at a lower load. A varus notched resurfaced femur was not tested because the load to failure was expected to be inferior. The presence of a notch at the proximal femoral cortex should be avoided, as there is a risk of fracture. If a notch is created intra-operatively, resurfacing arthroplasties should be converted to THAs.

Finite element studies have noted that the thickness and quality of the cement mantle affects load transfer in resurfaced femoral heads.[15,16] This potential source of variation was eliminated in our study.

It is useful to compare loads to failure with peak loads generated during gait. In normal gait, hip contact forces generally peak at approximately 3 times body weight.[17] During stumbling, these forces may reach as high as 9 times body weight.[18] For a 70-kg person, these equate to approximately 2100 N and 6300 N, respectively. In our study, the effect of torque, shear forces, surrounding muscle forces, and repetitive loads were not taken into account.

Failure of hip resurfacing may be associated with iatrogenic factors intra-operatively. The resurfaced head should be placed in an anatomic or valgus orientation, and the superior cortex of the femoral neck should remain intact. Should a notch be created intra-operatively, resurfacing arthroplasties should be converted to THAs.

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