



# IMPACT OF CEMENTLESS ZWEYMÜLLER STEM ANTEVERSION ON RESISTANCE TO PERIPROSTHETIC FRACTURE IN TOTAL HIP ARTHROPLASTY

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**SUMMARY** – Total hip arthroplasty implies proper orientation of both acetabular and femoral components with a range of 25-40° of combined anteversion. The aim of the study was to examine resistance to periprosthetic fracture of the axially loaded cross section rectangular femoral stem (Zweymüller) with respect to different degrees of anteversion, implanted in the artificial bone model, in laboratory conditions. Femoral bone models with implanted femoral stems were divided into 3 groups depending on the degree of stem anteversion (A, control group 13-17°; B, stem retroverted 0°-4°; and C, stem anteverted 26-30°). The amount of axial load leading to periprosthetic fracture (PPFx) of the artificial bone model was determined experimentally for each construct. The results showed that the load at which the PPFx occurred significantly increased with the increase of the endoprosthesis anteversion angle. In our clinical practice, we are often unable to place the acetabular component in an ideal grade of anteversion for intraoperatively determined reasons. The results of this experimental study suggested that increasing rectangular femoral (Zweymüller) stem anteversion lowered the risk of PPFx. This study was limited by experimental design (laboratory conditions, artificial bone) and should be clinically verified.

*Key words: Total hip arthroplasty; Periprosthetic fracture; Artificial bone model*

## Introduction

Total hip arthroplasty (THA), according to Learmonth *et al.*, has been declared the procedure of the century as compared to other operations<sup>1</sup>. With the exception of certain regions, implantation of cementless endoprosthesis is currently the leading procedure in the world<sup>2</sup>. According to numerous authors, rectan-

gular conical press-fit femoral component Zweymüller type endoprosthesis has proved to be durable with few perioperative and postoperative complications. Endoprosthesis of this type is fixed in the metaphysis and diaphysis region at four points, which provides the axial and rotational stability<sup>2-4</sup>. According to Mont classification, this endoprosthesis is classified as Mont 3C type<sup>2</sup>. During THA procedure, in order to prevent hip dislocation, about 10°-15° of femoral stem anteversion has to be achieved<sup>5</sup>. This value corresponds with the one reported in the anatomic study conducted on 100 adult cadavers, where combined acetabular and femoral anteversion averaged 29.6° in men and 33.5°

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in women, with femur anteversion  $11.6^\circ$  (men  $11.1^\circ$  and women  $12.2^\circ$ )<sup>6</sup>.

Periprosthetic fracture (PPFx) represents unwanted difficulty as one of major THA complications. PPFx after THA is one of the main causes of early stem failure and revision surgery. This complication is associated with higher patient morbidity and mortality<sup>7</sup>.

Since hip anteversion is often intraoperatively modified during THA, we wanted to test whether modification of anteversion affects occurrence of periprosthetic fracture in experimental conditions. Therefore, the aim of this study was to determine resistance to periprosthetic fracture of the axially loaded Zweymüller femoral stem with respect to different degrees of anteversion.

## Materials and Methods

### Femoral stem implantation

The femoral component used in this study was a Zweymüller endoprosthesis made of titanium alloy (Limacorporate S.p.A., Udine, Italy). The right synthetic femur (Synbone, Zizers, Switzerland) was used as the bone model in the experiment. Experimental testing was performed on artificial femoral bones in which femoral stem was implanted with various degrees of anteversion. All synthetic bones used in the experiment were identical, with anteversion angle of  $15^\circ$ . In the first step, neck osteotomy at the angle of  $45^\circ$  with respect to the neutral axis of the femur was made (Fig. 1A). Test specimens were divided into three groups depending on the femoral stem anteversion angle, as follows: group A (physiological anteversion,  $13^\circ$ - $17^\circ$ ), group B (decreased anteversion,  $0^\circ$ - $4^\circ$ ), and group C (increased anteversion,  $26^\circ$ - $30^\circ$ ) (Fig. 1B)<sup>5</sup>. After femoral canal reaming, femoral stem was implanted accordingly with instrumentation provided by the manufacturer. According to the bone model x-ray, size 4 of the implant endoprosthesis was selected for this experiment (Fig. 1C). The endoprosthesis was positioned so that the center of the head was in the plane passing through the tip of the large trochanter and parallel to the upper surface of the endoprosthesis body.

### Construct preparation for mechanical testing

After stem implantation, a transverse cut was made at a distance of 340 mm from the tip of the greater trochanter for later fixation of the specimen itself (Fig. 1A).

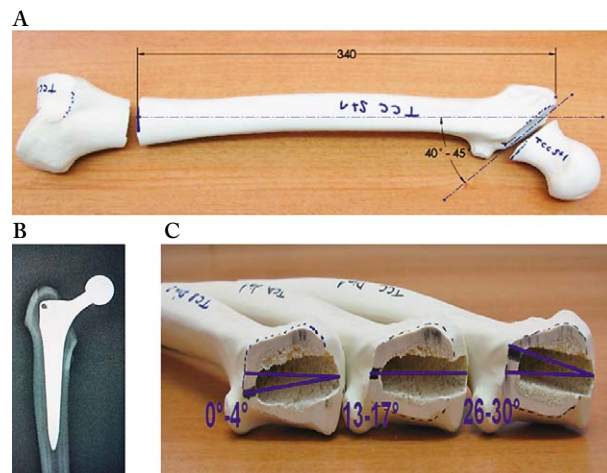


Fig. 1. (A) Osteotomies on a synthetic femur model (Synbone, Zizers, Switzerland); (B) assembly x-ray; (C) anteversion angles according to model groups (TCA  $13$ - $17^\circ$ , TCB  $0$ - $4^\circ$ , TCC  $26$ - $30^\circ$ ).

Constructs were spatially positioned in the frontal plane at the angle of  $8^\circ$  lateral to the vertical axis (Fig. 2a) and in the sagittal plane at the angle of  $6^\circ$  dorsal to the vertical axis, thus mimicking femoral position during gait<sup>15</sup> (Fig. 2b). Once the model was positioned, distal femur was molded into SCS-Beracryl D28 medium (Suter Kunststoffe AG, Switzerland). The plane to which the model was embedded in the fixing medium was located 250 mm from the tip of the great trochanter. That particular distance was determined to allow the assembly to be sufficiently tight to withstand stresses of the test and the fixed position sufficiently distant from the point where the load was transferred

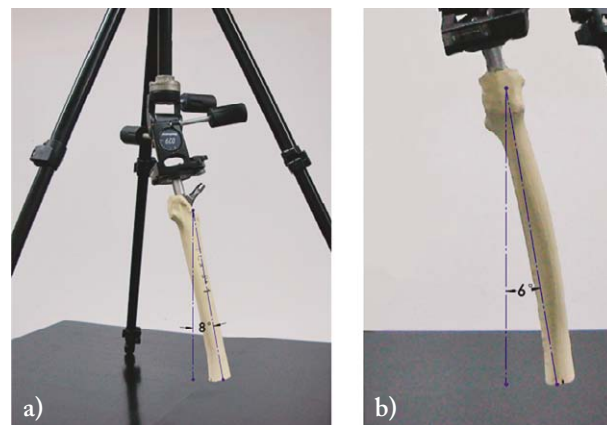


Fig. 2. Spatial positioning of the femur: (a) position of femur in frontal plane; (b) position of femur in sagittal plane.

from the endoprosthesis to the bone to minimize measuring distortion.

### Mechanical testing

The test was performed on a static Beta 50-5 testing machine (Messphysik, ZwickRoell Testing Systems GmbH, Fürstenfeld, Austria) (Fig. 3). A four-point clamping head was mounted on the machine table to secure model position during testing. The specimen was positioned so that the vertical load axis of the machine passed through the center of the endoprosthesis head. The loading rate was determined to be 10 mm/min. All specimens were submitted to axial



Fig. 3. Experimental setup for mechanical testing.

compressive load and were tested until periprosthetic fracture occurred. Mechanical properties of bone implant materials are given in Table 1<sup>8,9</sup>.

For better insight into the distribution of displacements and stresses throughout the test model, computer simulation was performed using the finite element method. Static load approximately equivalent to that of the load on the femur when a person of an average body weight is standing on two legs was simulated. By reconstructing the geometry from computed tomography images, we constructed a 3D model of the femur, while the endoprosthesis model Standard for the Exchange of Product Data (STEP) files were provided by the manufacturer (Lima Ltd., Udine, Italy). The parameters used in computer simulations were validated by comparing the displacements obtained with displacements recorded by the Aramis optical measuring system during the experimental test<sup>10</sup>.

### Results

The values of the axial compressive load at which periprosthetic fracture of the femur occurred in the specimen groups are shown in Table 2. The axial load *versus* displacement diagrams recorded during the static test experiment are shown in Figure 4.

The lowest mean fracture load ( $2533 \pm 106.1$  N) was observed in group B (anteversion angle  $0-4^\circ$ ). In group A (anteversion angle  $13-17^\circ$ ), the mean value of the

Table 1. Mechanical properties of materials

Part of the bone implant assembly	Material	Elastic modulus $E$ [MPa]	Poisson's ratio $\nu$
Endoprosthesis stem	ISO 5832-3	110000	0.3
Cortical bone	Polymer	17000	0.3
Cancellous bone	Polymer	1300	0.3

Table 2. The force and displacement values at which periprosthetic fracture occurred

Test specimen	Group A		Group B		Group C	
	$F_a$ [N]	$w$ [mm]	$F_a$ [N]	$w$ [mm]	$F_a$ [N]	$w$ [mm]
Specimen 1	2516	13.48	2538	12.26	3001	11.23
Specimen 2	2684	11.23	2636	10.89	2891	12.20
Specimen 3	2576	11.73	2424	11.82	2853	12.81
Mean value	2592	12.15	2533	11.66	2915	12.08
St. deviation	85.14	1.181	106.1	0.669	76.86	0.797

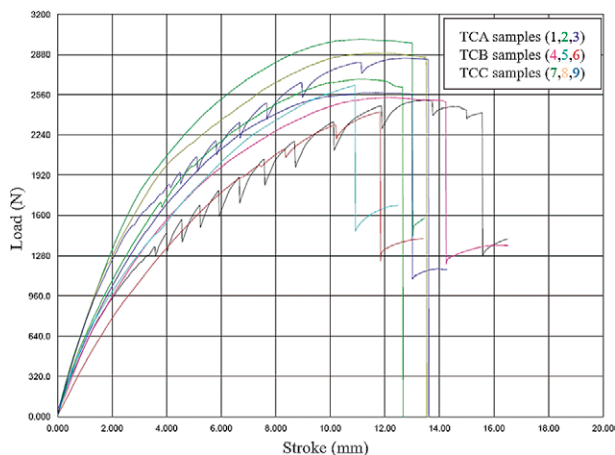


Fig. 4. Axial load-displacement diagrams.

fracture load was  $2592 \pm 85.14$  N, and a significantly higher mean load value ( $2915 \pm 76.86$  N) was recorded in group C (anteversion angle  $26-30^\circ$ ). The results showed the load at which the periprosthetic fracture occurred to increase significantly with the increase of the endoprosthesis anteversion angle (in the range of  $0^\circ-30^\circ$ ). While conducting the experiment, during implanting femoral components two periprosthetic fractures occurred in TCB models.

## Discussion

The results suggested that increasing rectangular femoral (Zweymüller) stem anteversion lowered the risk of PPFx in THA. The main finding of this study was that adding cementless Zweymüller stem anteversion raised resistance to PPFx in THA in experimental conditions on artificial bone model. In our clinical practice, for intraoperatively determined reasons (acetabular wall deficiency, post-traumatic or post infectious conditions, etc.), we are often unable to place the acetabular component in an ideal grade of anteversion. To respect combined anteversion, we can modulate femoral stem anteversion in that case; however, as assumed by the authors, it will affect the construct PPFx risk.

There are no biomechanical studies or similar studies in the literature that would examine the periprosthetic fracture risk of the Zweymüller cementless endoprosthesis relative to the degree of anteversion. Kolb *et al.* recently published a 20-year follow-up study of Zweymüller type of endoprosthesis with 96% of 20-year survival<sup>4</sup>. The notion of anteversion by studying hip anatomy was firstly introduced by McKibbin in a study con-

ducted on pediatric cadavers and defined  $30^\circ$  to  $40^\circ$  combined anteversion as normal, with  $15^\circ$  anterior femoral neck anteversion<sup>11</sup>. The use of Zweymüller endoprosthesis compared with neck preserving endoprostheses shows no differences in long-term outcome by measuring pain and patient satisfaction surveys<sup>12,13</sup>. According to Veen *et al.*, the use of this endoprosthesis has proven useful in advanced age patients (80-year-olds) with an average of 6.5 years of postoperative course without complications<sup>14</sup>. On the other hand, in a randomized clinical study comparing hip hemi-arthroplasty of the cemented femoral component with the Zweymüller cementless component, Taylor *et al.* report a significantly higher number of implant-related complications (periprosthetic fractures, etc.), as well as a longer duration of postoperative pain in patients who had a cementless endoprosthesis implanted<sup>15</sup>. In younger age groups (mean age 61.1), Vervest *et al.* describe survival of the indicated form of the femoral component of 96% through 10 years of postoperative follow-up<sup>16</sup>. Reviewing the literature on biomechanical *in vitro* studies related to this type of the femoral component of endoprosthesis, Bieger *et al.* on a cadaveric bone model showed that the mini-invasive shape of the Zweymüller femoral component with a reduced trochanteric ridge did not show difference in primary axial stability from the original design, but did show deviations in rotational stability<sup>17</sup>. Using densitometric analysis, Hayashi *et al.* confirmed the loss of periprosthetic bone mass in cone short-stem with lower anteversion in a prospective study on 44 patients<sup>18</sup>. Perioperative PPFx are strongly correlated with the fixation method; analysis from the American Joint Replacement Registry showed the PPFx incidence of 12%. PPFx are three times more common with uncemented stems (19%) than with cemented stems (6%) ( $p < 0.001$ )<sup>19</sup>.

In need of lowering femoral component anteversion, one should be careful with the rectangular femoral stem (Zweymüller) type, as shown by our results. Results of the experimental testing indicate a trend of increasing the amount of force at which periprosthetic fracture of the femur occurs when the angle of anteversion is increased (ranging from  $0^\circ$  to  $30^\circ$ ). The authors suggest that femoral bone anatomy (anteversion and antecurvatum) cannot tolerate stresses caused by implanting the rectangular femoral component in retroverted position (anteversion angle  $0^\circ-4^\circ$ ) and it is more prone to fracture.



The biggest absolute shift occurs on the cone of the neck of the endoprosthesis. As shown in the experimental study, a trend of displacement decrease with the increase in anteversion angle is visible. On the model with anteversion angle 0–4°, a 56% increase is recorded over the model with the anteversion angle of 26–30°. A comparison of displacements of the endoprosthesis-bone model before and after the healing process was made with no significant differences in the displacements between the sample groups observed. Contact stresses generated at the site of the endoprosthesis-bone contacts were not considered in this study. By comparing stress at the neck reported in the literature as a critical site of the endoprosthesis, no significant differences were observed across model groups.

As it is often necessary to modify anteversion of the acetabular component of the endoprosthesis for intraoperatively determined reasons (anatomic variations, defect of the posterior wall of the acetabulum, etc.), the biomechanical relationships can be partially compensated for by altering anteversion of the femoral component.

This study had several limitations. The experiment was performed on artificial bones and osseointegration was not considered. Sample size should be extended in future studies.

In our clinical practice, for intraoperatively determined reasons, we are often unable to place the acetabular component in an ideal grade of anteversion. The results of this experimental study suggest that increasing rectangular femoral (Zweymüller) stem anteversion lowers the risk of PPFx. This study was limited by experimental design (laboratory conditions, artificial bone) and should be clinically verified.

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## Sažetak

## UTJECAJ ANTEVERZIJE BESEMENTNE ENDOPROTEZE ZWEYMÜLLER NA OTPORNOST PERIPROTETSKOM LOMU PRI POTPUNOJ ZAMJENI KUKA

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Potpuna zamjena kuka podrazumijeva pravilnu orijentaciju acetabularne i femoralne komponente u rasponu od 25°-40° kombinirane anteverzije. Cilj ovoga istraživanja bio je ispitati otpornost na periprotetski prijelom aksijalno opterećene femoralne komponente endoproteze kuka tipa Zweymüller, pravokutnog poprečnog presjeka s obzirom na različite iznose kutova anteverzije, ugrađene u model umjetne kosti pri laboratorijskim uvjetima. Modeli femura s ugrađenim endoprotezama podijeljeni su u tri skupine ovisno o stupnju anteverzije endoproteze (A, kontrolna skupina 13°-17°; B endoproteza u retroverziji 0°-4°; C, endoproteza u anteverziji 26°-30°). Iznos aksijalnog opterećenja koje dovodi do periprotetskog prijeloma umjetne kosti određen je eksperimentalno za svaki sklop. Rezultati su pokazali da se opterećenje pri kojem je došlo do periprotetskog prijeloma znatno povećalo s povećanjem kuta anteverzije. U našoj kliničkoj praksi često nismo u mogućnosti pozicionirati acetabularnu komponentu u idealan stupanj anteverzije iz intraoperativno određenih razloga. Rezultati ove eksperimentalne studije pokazuju da povećanjem anteverzije pravokutne femoralne (Zweymüller) endoproteze dolazi do smanjenja rizika od periprotetskog prijeloma. Ova studija je ograničena eksperimentalnim dizajnom (laboratorijski uvjeti, umjetna kost) i traži kliničku verifikaciju.

Ključne riječi: *Umjetni zglob kuka; Femoralna komponenta Zweymüller; Anteverzija; Periprotetski prijelom*