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HIP ARTHROPLASTY

Primary stability of total hip stems: does surgical technique matter?

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Abstract

Background With this preliminary study we hypothesized a modified implantation technique may lead to higher primary stability than the conventional one.

Methods In the conventional technique we used a sharp spoon to open the femoral cavity. Subsequently the opening was extended by increasing sizes of a sensing device to approve the final size. Finally, a bone compactor of the corresponding size was inserted in the cavity preparing it for implantation while compressing the surrounding cancellous bone. After initial opening of the femoral canal with a sharp spoon, the modified implantation technique was characterized by direct use of increasing sizes of bone compactors. A standardized procedure was implemented for micromotion analysis using LVDT's. Each specimen was positioned in a servo-hydraulic testing machine following a standardized test regime. A total of 1500 load cycles with a maximum hip reaction force of 1000 N were applied on each sample in three series of 500 cycles. The force was applied as a cyclic sinusoidal with a frequency of 1 Hz and a load ratio of $R = 0.1$.

Results No significant differences of micromotion between implant and surrounding bone stock could be detected regarding conventional vs. modified implantation technique. However, independent of the surgical technique used, significant differences were observed for the operated side, i.e. backhand driving of right-handed surgeon resulted in higher interfacial micromotions at the left side.

Conclusion The results did not support our hypothesis. However, the correlation found between operated side and surgeon's backhand driving as a potential risk for reduced primary stability should encourage further investigations.

Keywords Total hip replacement · Micromotion · Primary stability · Short femoral stem · Surgical technique

Introduction

The mean age of patients requiring total hip replacement is constantly decreasing. The Swedish Hip Arthroplasty Register reports a 75% implant survival of 14 years for male patients younger than 50 years, compared to a survival rate of 84% for male patients between the ages of 60 and 75 [1]. Although the reason for failure in the group of young patients is multifactorial, short-stemmed femoral prostheses have the theoretical advantage of preserving bone at the initial implantation and ideally maintain this amount of bone over time for upcoming revisions. Proximal load transfer to the trochanteric region should, therefore, probably be the aim in modern implant designs such as short femoral-neck prostheses, which claim less interference with the biomechanics of the proximal femur. Nevertheless, there are reasons for reflecting on the relatively new concept of short femoral stems. Successful total hip replacement (THR) requires stable initial and long-term axial and rotational fixation. Short stems prevent complications with proximal–distal mismatch, femoral bowing or diaphyseal deformities, and preexisting hardware. Short femoral designs offer the opportunity to reduce violation to the adjacent bone and surrounding soft tissue envelope following less invasive surgical approaches. Restoring femoral off-set in short stem designs is alternatively based on a variety of curved stems in an implant family similar to conventional stems or on different levels of neck resection combined with a slight valgus or varus position of the implant. Therefore, short stems can roughly be divided into a collum preserving group, solely

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anchoring on the metaphysis, and a short collum preserving group, anchoring on the metaphysis with short anchorage on the diaphysis. The former principle not only ensures axial stability but also has a better impact on rotational stability. In an experimental study in 1993, Jasty et al. described the potential for abstinence of diaphyseal anchorage once a standard implant has accomplished proximal fixation [2]. Further, work was published in 1995 by Whiteside et al. [3], who tested in vitro different levels of femoral neck preservation and their ability to neutralize torsional load of the femoral component. Preservation of 50% or more of cortical neck was able to produce acceptable micromotions, while 15% or less produced micromotions with conventional designs [3]. Reasons for variation in implant survival rates may be linked to the implantation technique which is demanding and prone to the surgeon's back- or forehand with potential drawbacks to implant fixation and primary stability. Increased interfacial micromotions may jeopardize the long-term postoperative result. Therefore, initial implant stability achieved during primary surgery is essential for sufficient bone ingrowth. In an animal model, Pilliar et al. provided proof of complete osseus implant integration on micromotions up to 28 µm and failure of integration on micromotions exceeding 150 µm [4]. These results were confirmed by Burke et al. in an experimental study defining micromotions of less than 40 µm as the "threshold of bony ingrowth" [5]. According to Noble et al. [6], cementless femoral designs seldom achieve an initial interfacial bone-implant contact of more than 20%.

Increased risk of insufficient primary stability may also result from errors in surgical techniques such as the use of inadequate instruments or aggressive reaming right through to the counter-cortex with loss of biomechanically competent cancellous bone. Clinical evidence supports the correlation between primary stability of endoprosthetic implants and postoperative loosening and premature failure. Thus, stability is paramount to the long-term implant survival [7, 8]. With the present preliminary study, we aimed to analyze whether a different implantation technique optimizes primary implant stability of short total hip stems and, therefore, have the potential to reduce risk of aseptic loosening.

Methods

This study comprised a total of 16 paired fresh frozen human cadaveric femora as summarized in Table 1. Pre-operative radiographs were used for pre-surgical planning, size and curvature identification. All bones were adequately thawed for 6 h at room temperature prior to the stem implantation. One bone of each pair randomly received an implant using the conventional implantation technique, while the contralateral implant was inserted with a modified technique. With the conventional technique opening of the femoral cavity starts with a sharp spoon and subsequently is extended by increasing sizes of a sensing device to approve the final implant size. As a final step a bone compactor of the corresponding size is inserted in the cavity to prepare it for the stem implant while compressing the surrounding cancellous bone. After initial opening of the femoral canal with a sharp spoon, the modified technique is characterized by direct use of increasing sizes of bone compactors. Both implantation techniques were distributed for each side randomly as shown in Table 1 providing equally sized sample groups. After approval by the institutional review board (ethical committee of University of Rostock—A 2010 11), the implantations were performed by an experienced right-handed orthopaedic surgeon. The bone specimen were stored at − 18 °C until further mechanical testing. A standardized test procedure was used for the micromotion analysis at the interface between implant and bone stock. A 6 mm circular opening was created 15 mm below the Trochanter minor in each sample, providing access to the underlying implant. A 2.5 mm hole, concentric to the bone opening, was drilled in the implant, a thread was cut into the metallic stem, and a measuring pin was firmly attached to the implant.

The distal part of the femoral bone specimen sample was then embedded into a fixture, using a fast curing polymer system (RenCast® FC 52 Isocyanat and FC 52 Polyol with Filler; Huntsman Advanced Materials, NY, USA). A micromotion measuring device developed in-house, consisting of four linear variable differential transformers (LVDT's) (DP5S, Fa. Solartron Metrology, Meerbusch, Germany), was

Table 1 Synopsis of 8 femoral pairs (II-1 to II-8), (L = left, R = right), (C = classic, M = modified), (Fx = fractured during implantation)

Femur-ID	Stem size	Stem curvature	Impl.-method	Comment
II-1-L	S	A	C	
II-1-R	S	A	M	
II-2-L	XS	A	C	
II-2-R	XS	A	M	
II-3-L	S	B	C	
II-3-R	S	B	M	
II-4-L	XS	B	C	
II-4-R	XS	B	M	
II-5-L	XS	A	M	
II-5-R	XS	A	C	
II-6-L	S	A	M	
II-6-R	S	A	C	
II-7-L	ML	A	M	
II-7-R	–	–	–	Fx
II-8-L	XS	A	M	
II-8-R	XS	A	C	

Stem sizes: *xs* extra small, *s* small, *ML* medium large

attached to the bone, and the tactile tips of the LVDT's were connected to the orthogonal surfaces of a measuring Block, rigidly connected to the End of the measuring pin as shown in (Fig. 1(4)).

Each sample was tested following a standardized protocol, which included measuring pin fixation, embedding, curing of the embedding medium to give equal thaw time to each sample, thereby providing mechanical properties as similar as possible. Following this testing protocol, each specimen was positioned in a servo-hydraulic testing machine (Instron FastTrack 8874, Fa. Instron Pfungstadt, Germany) and was adjusted appropriately so that the force actuator of the test machine was angled according to the maximum resultant force orientation (heel-strike), relative to the femur, described by Bergmann et al. [9]. A femoral head with 32 mm diameter was used to apply the mechanical load onto the implant interface sample (Fig. 1(5)). A standard titanium acetabular cup with a 32 mm diameter polyethylene insert was embedded into a fixture similar to the bone samples with an angulation of 45° to the load axis to simulate the load transmission in a standard THR (Fig. 1(6)) while the transmission of shear forces was prevented by an axial bearing between the force actuator and the acetabular fixture (Fig. 1(7)). A total of 1500 load cycles with a maximum hip reaction force of 1000 N were applied to each sample in three series of 500 cycles. The force was applied as a cyclic sinusoidal with a frequency of 1 Hz and a load ratio of $R = 0.1$. Four translational displacements were recorded with a frequency of 20 Hz for the duration of each series. Subseries of 50 cycles at the beginning, the middle and the End of each series were used to calculate the average magnitude of the interfacial micromotion between implant and surrounding bone.

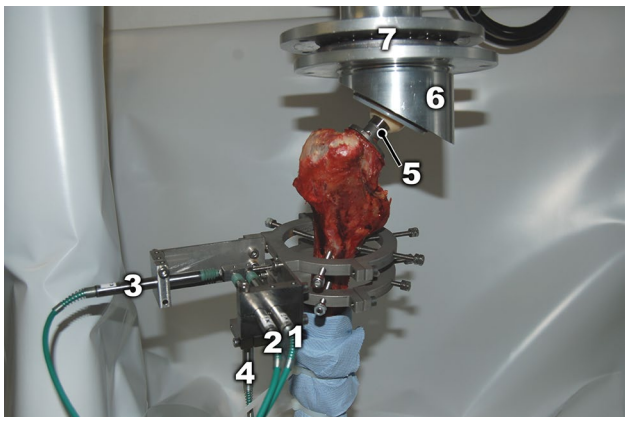

Fig. 1 Micro-motion measuring device with LVDT's attached to the bone. The tactile tips of the LVDT's were connected to the orthogonal surfaces of a measuring Block, rigidly connected to the End of the measuring pin

To compare the classic with the modified implantation technique, statistical analysis with SPSS software (SPSS 2.0, IBM, Ehningen, Germany) was performed. The level of significance was set to $p = 0.05$.

Results

15 of 16 bone specimens maintained their integrity during mechanical testing. Thereby no implant failure was observed up to 1500 load cycles. Mean values and standard deviations of both implantation techniques are listed in Fig. 2. Differences of mean value of both groups were small, but standard deviation of the conventional technique was lower. Mean values of micromotion over 1500 cycles did not show any significant differences in general, with 0.161 mm for the modified and 0.162 mm for the conventional technique ($p = 0.67$), nor with regard to the three subseries of 500 cycles. Independent of the implantation technique used, significant differences of micromotions were observed for the operation side with higher values for the left hip (Fig. 3). Looking at interspecimen variation of micromotions results showed differences in the distribution of micromotions across the specimens (Kruskal–Wallis-test for independent samples: $p = 0.002$ for evaluation ranges of 500 cycles and $p = 0.000$ for evaluation ranges of 50 cycles). Pairwise comparison of the results showed significant differences for the bone specimens 4, 5 and 8 (Mann–Whitney U test for independent samples, Table 2).

Discussion

As total hip arthroplasty is linked to a certain percentage of complications, attention has to be taken to identify the source of implant failure with regard to acceleration of surgeon´s learning curve and to improve surgical technique or implant design. Concerns about potential metaphyseal bone loss of diaphyseal anchoring implants led to a demand for short total hip stems that preserve bone at the anatomic curvature of the femoral neck and restore biomechanical proportions better than conventional stem designs. On the other hand, tissue-sparing and minimally invasive approaches may be easier with small curved stems. Consequently, various short femoral stems have been introduced over the last decade, with these involving different concepts of fixation, reproducibility of the patient's coxal anatomy, and osteologic competence. The goal of tapered conventional hip stems is to load the proximal femur, and biomechanical properties of the majority of short stemmed femoral prostheses are based on the same philosophy of performing this task. There has not yet been a proper classification of short femoral stems, and we have to acknowledge that comparison of biomechanical

Table 2 Correlation table comparing micromotion results (averaged over subranges of 50 cycles in the lower left, averaged over 500 cycles in the upper right) from one donor to a second (*p*-values of Mann–Whitney *U* test for independent samples)

Average of 50 cycl	Average of 500 cycl.						
	1	2	3	4	5	6	8
1		0.394	0.818	**0.002**	0.180	1.000	**0.026**
2	0.097		0.699	**0.002**	0.065	0.485	0.240
3	0.815	0.161		**0.002**	0.240	0.589	0.485
4	**0.000**	**0.002**	**0.000**		**0.026**	**0.002**	**0.002**
5	**0.017**	**0.002**	**0.029**	**0.000**		0.180	**0.004**
6	0.650	0.252	0.406	**0.000**	**0.013**		0.240
8	**0.000**	**0.040**	**0.031**	**0.000**	**0.000**	**0.024**	

Bold numbers identify significant differences

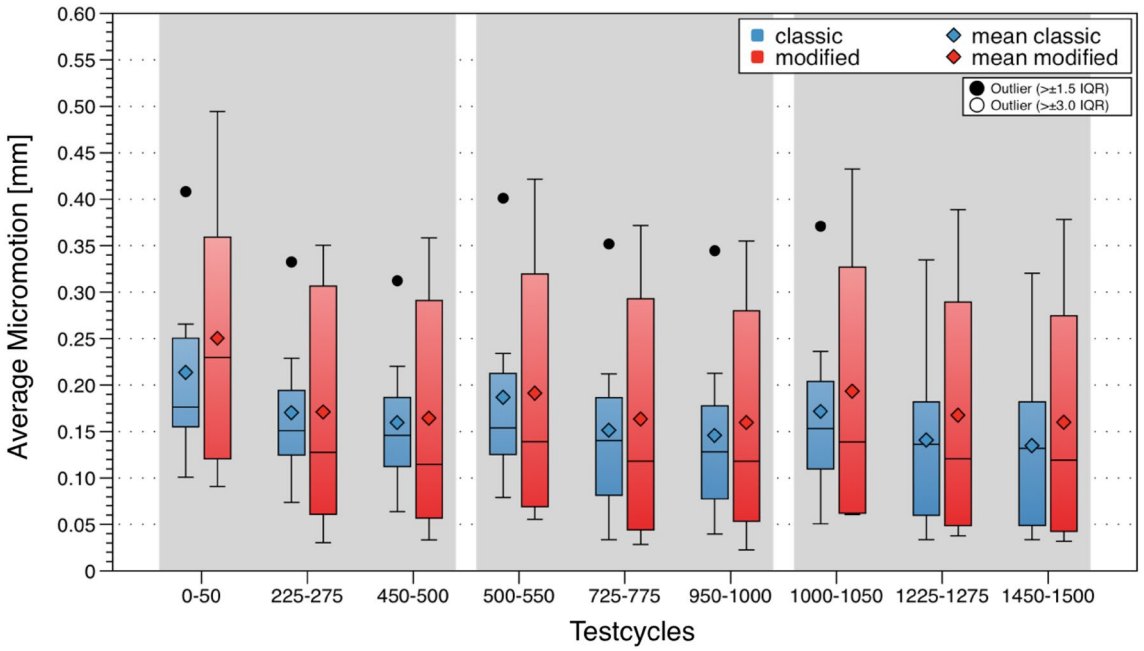

Fig. 2 Comparison of averaged micromotions of all samples of classic and modified implantation technique

and clinical results has a certain lack of significance. But there is a wide consensus that failure of total hip implants is mostly due to aseptic loosening as described above [10, 11]. The collum femoris preserving (CFP) stem (Fig. 4) is based on a prototype introduced by Pipino and Calderale (1987) and aims to retain subcapital parts of the femoral neck to achieve physiological load transfer along the trabecular systems by distributing the stress towards the medial and lateral diaphysis while resting on the calcar. The published results of the CFP stem are promising, i.e. the majority of clinical studies with short to mid-term results (3.1–9.3 years) did not report cases of aseptic implant loosening [12–22].

Based on the literature search, we found three publications on CFP stems which specified aseptic loosening in their list of complications [23–25]. Falez, Casella and Papalia summarized clinical results for short collum preserving implants. Amongst other causes of failure, four of these studies describe mechanical loosening of the stem in a small number of cases [26–29]. Factors promoting early loosening of hip implants are largely determined by patient, implant design, material and fixation, and finally operation technique. Furthermore, a surgeon's experience and practice are estimated to have a great impact on primary implant stability. The primary stability of cementless stems has been evaluated in vitro or with numerical models several times. Most of the testing protocols have straightened one or two motor tasks in vitro such as stair climbing or other tasks with similar torque stresses which are most challenging with regard to stem stability [5, 29–31]. Depending on the extent of stability achieved and on the stem design, inducible micromotions in the range of 10–300 µm were found for comparable loading conditions on uncemented

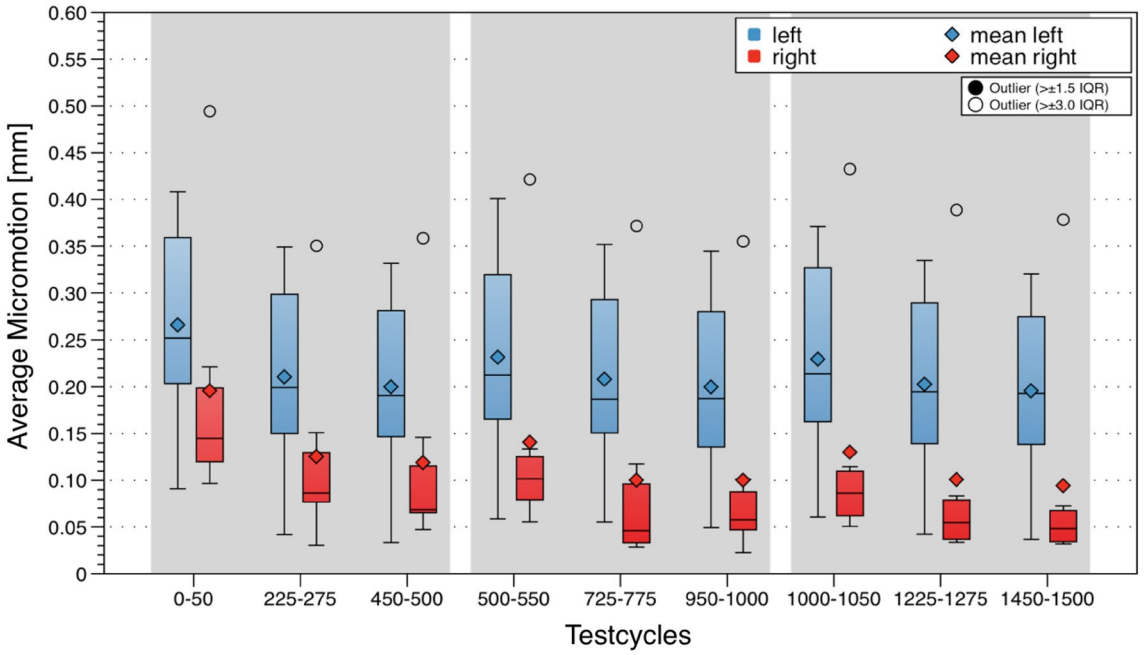

Fig. 3 Comparison of averaged micromotions of all samples of right and left side

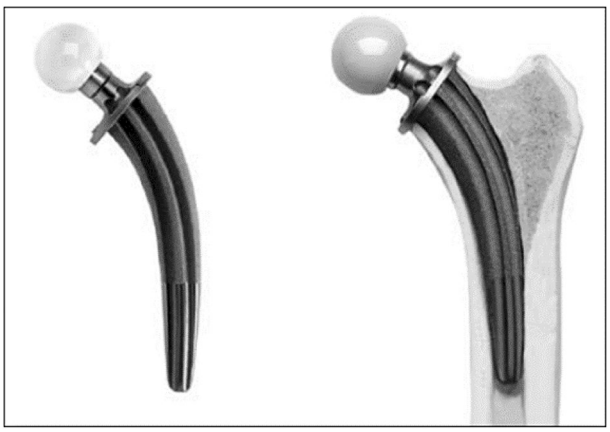

Fig. 4 Collum femoris preserving stem with ceramic femoral head (Waldemar Link®, Hamburg, Germany)

implants in cadaveric human specimens in vitro [5, 32–34]. Similar results were reported on ex vivo specimens with range from 4 to 300 µm in 1–17 year retrievals [29, 35]. There is general agreement that implant stability should be assessed under combined loading conditions, axial compression, and sagittal and coronal bending. Only a few investigations have opted for torsional loading in the absence of any axially directed force. Hua and Walker in a comparative in vitro study showed that a symmetrical stem had over ten times more relative rotational motion than did the other two stems, an asymmetrical and a custom asymmetrical stem [36]. According to Harris WH et al. torsional loads from daily activities such as stair climbing or getting up from a chair, are known to be most responsible for initial rotational instability in femoral implants [37]. Nunn and co-workers in their study could show that preservation of the femoral neck and use of a ridged prosthesis increases resistance to rotation [38]. The risk of rotational instability was confirmed by Glisson et al. who observed relative motion of 61 µm under axial and over 100 µm under torsional load [39].

In our present preliminary biomechanical study, we attempted to optimize the implantation technique of a short femoral hip implant likely to achieve a further decrease in aseptic loosening. Usually in vitro studies are carried out under ideal conditions and tend to focus on dependence of stress distribution or stability in the prosthetic design more than on surgical parameters. In a few studies the effect of surgical factors was explored such as stem insertion depth or intraoperative fractures with the latter ones being associated to a learning curve [31, 40]. According to this, the present study interestingly identifies an unexpected potential risk of aseptic loosening. Independent of the technique that was used, significant differences of micromotion were observed for the operated side with higher values on the left. This might be due to the surgeon's favoured impact driving using the posterior approach, more precisely backhand on left and forehand on right hips. An explanation for this might be due to the biomechanics of the elbow described by Roetert et al. (1995) with special regard to backhand technique triggering lateral epicondylitis in tennis players [41]. As seen by Groppel and Mason, an inadequate distance between body and

racket with ball contact far from the fulcrum lever (shoulder) during strike leads to strong torque forces, which in turn cause rapid arm and shoulder fatigue [42, 43]. Additionally, unskilled players will have more miss-hits near the periphery of the racket compared to skilled players [44]. In the broader sense, backhand impact driving on left hips might have been influenced by arm and shoulder fatigue and more or less miss-hits on the implant driver, finally resulting in higher values of micromotions on left hip implants in our present study.

Conclusion

In summary, we tried to evaluate whether opening of the femoral cavity by a sharp spoon and subsequently extending it by increasing sizes of a sensing instrument with expulsion of spongious bone distal may lead to an implant bone interface of inferior stability compared to that of the modified procedure. Our results did not support this hypothesis and our study also has some limitations like a small sample size resulting in relatively high standard deviation. We also did not opt for mechanical testing under torsional load which might have given rise to significant joint reaction forces described by Berzins et al. [45]. Furthermore, with regard to average micromotions being similar in both implantation techniques a few cases included outliers not representing primary stability even though this is to be seen critically in response to mean values. Independent of the surgical technique used in our study, significant differences were observed for the operated side, i.e. backhand driving of right-handed surgeon resulted in higher interfacial micromotions at the left side. However, the correlation found between the operated side and the surgeon´s backhand driving as a potential risk for reduced primary implant stability should encourage further biomechanical investigations with electromyography and motion analysis of back- and forehand driving focussing on resultant forces and power of impact of the hammer.

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