Biomed Tech 2012; 57:169–174 © 2012 by Walter de Gruyter • Berlin • Boston. DOI 10.1515/bmt-2011-0066

Primary stability of cementless threaded acetabular cups at first implantation and in the case of revision regarding micromotions as indicators

Andreas Bürkner[1,*], Andreas Fottner[2], Thomas Lichtinger[3], Wolfram Teske[3], Tobias Vogel[3], Volkmar Jansson[2] and Christoph von Schulze Pellengahr[3]

[1] Klinik für Orthopädie und Unfallchirurgie, Klinikum Freising, Alois-Steinecker-Straße 18, 85354 Freising, Deutschland
[2] Orthopädische Klinik und Poliklinik, Klinikum Grosshadern, Ludwig-Maximilians-Unversität, Marchioninistraße 15, 81377 Munich, Deutschland
[3] Orthopädische Universitätsklinik, St. Josef-Hospital, Kliniken der Ruhr-Universität Bochum, Gudrunstraße 56, 44791 Bochum, Deutschland

Abstract

The primary stability of cementless total hip endoprosthesis is of vital importance for proximate, long-term osteointegration. The extent of micromotions between implant and acetabulum is an indicator of primary stability. Based on this hypothesis, different cementless hip joint endoprosthesis were studied with regard to their micromotions. The primary stability of nine different cementless threaded acetabular cups was studied in an experimental setup with blocks of rigid foam. The micromotions between implant and implant bearing were therefore evaluated under cyclic, sinusoidal exposure. The blocks of polymer foam were prepared according to the Paprosky defect classifications. The micromotions increased with the increasing degree of the defect with all acetabuli tested. Occasionally coefficients of over 200 µm were measured. From a defect degree of 3b according to Paprosky, the implants could no longer be appropriately placed. The exterior form of the spherical implants tended to exhibit better coefficients than the conical/parabolic implants.

Keywords: micromotions; primary stability; revision; threaded cup; total hip endoprosthesis.

Introduction

Sufficient primary stability of an endoprosthesis is the essential condition for proximate osteointegration and thus also for long-term secondary stability. Primary stability can be achieved in different ways biomechanically. The primary stability of threaded implants is based on a press-fit situation by a thread being screwed into the bone. Some studies have shown an increased rate of migration and loosening of threaded hip endoprosthesis [9, 10]. Due to those high migration rates, the design of some of the cups has been abandoned and some have been modified, leading to diverging clinical results. The complexity of the market for total hip joint endoprosthesis and lack of long-term results of new concepts have led to the search for an experimentally analysable parameter for the primary stability of hip joint endoprosthesis being of distinctive clinical importance.

The parameters chosen in this study are the micromotions between the implant and the implant bearing occurring when the implant is loaded. Schneider and Pitto state that the effect of micromotions between implant and implant bearing can cause resorption of the bone and thus loosening and failure of the implant [20, 22]. As most acetabuli that are operated on are partly or completely destroyed by osteoarthritis, different stages of osteodestruction have been simulated and examined.

Materials and methods

To experimentally identify the micromotions that occur, nine of the most common cementless threaded implants were analysed and compared (see Table 1). The data are based on the market share in Germany, according to details from the manufacturers.

As the mechanical properties of human bone show a wide variation depending on age and location, and the availability of bone samples is limited, polymer foams are used as an alternative. Polymer foams have been used in several *in vitro* experiment simulating cancellous bone [7, 8, 12–14]. In this study, blocks of rigid foam made of densely linked PVC rigid foam (Herex C70, C70.200 Airex AG, Sins, Switzerland) were used to model the acetabulum. This specific foam has previously been used and examined in studies based on the stiffness to strength ratio in a similar range to that of cancellous bone [8, 15, 23, 27]. The polymer foam was cut into blocks of 10×10×5 cm. The cavity of the human acetabulum was modelled by milling the centre the blocks with a 48 mm spherical moulding cutter. Revisions were modelled by adopting the classifications defined by Paprosky [16] (Figure 1):

- Defect type 0 describes the intact acetabulum.
- Defect type 1 is described by an intact rim, but with focal areas of contained bone loss.

---

*Corresponding author: Andreas Bürkner, Klinik für Orthopädie und Unfallchirurgie, Klinikum Freising, Alois-Steinecker-Straße 18, 85354 Freising, Deutschland
Phone: +81 61243000
Fax: +81 61243099
E-mail: andreas_buerkner@gmx.de

Table 1 Threaded implants that were tested.

Implant	Manufacturer	Exterior form	Material
Lamella	Zimmer, formerly Centerpulse	Spherical	Titanium
Schraubring SC	Aesculap	Spherical	Ti 6Al 4V
Schraubring München II	Aesculap	Spherical	Titanium
Ultima	Johnson and Johnson	Spherical	Ti 6Al 4V
Zintra	Zimmer	Spherical	Ti 6Al 4V
Alloclassic	Zimmer, formerly Centerpulse	Parabolic	Titanium
Bicon plus	Endo plus	Parabolic	Titanium
Hofer Imhof	Smith and Nephew, formerly Intraplant	Parabolic	Titanium
Variall	Zimmer, formerly Centerpulse	Parabolic	Titanium

- Defect type 2 is defined by a distorted, but intact rim; the further Paprosky subcategories were not applied here.
- Defect type 3 is characterised by an inadequate acetabular rim for the initial stability of hemispherical implants. Type 3b has a rim defect greater than half of its circumference.

Using these criteria, one model block for each defect type was modelled by hand using a ball-shaped cutter. The model was filled with cement. The resulting negative was the blueprint used to inspect all further blocks after preparation. For each implant, five blocks of rigid foam per defect type were prepared using the method described above.

After the preparation of the acetabuli, each foam block was reamed with an acetabular reamer of 50 mm external diameter, as recommended by the manufacturers. To accomplish this, a base plate was installed in a metal frame that could be moved vertically by a gear drive and a cable winch. Through the weight placed on the cable winch, a constant grinding pressure can be created during reaming and threading. On the base plate, a drill chuck was mounted in the centre to clamp the acetabular reamer and inserter handle of the implants. The drill chuck was linked by a gear mechanism to a revolutions per minute (rpm)-regulated electric motor, which was operated via a control unit installed on the side. Thus the implants were inserted with a perfect fit in a standardised fashion and mechanically with 15 rpm and a constant contact pressure of 100 N.

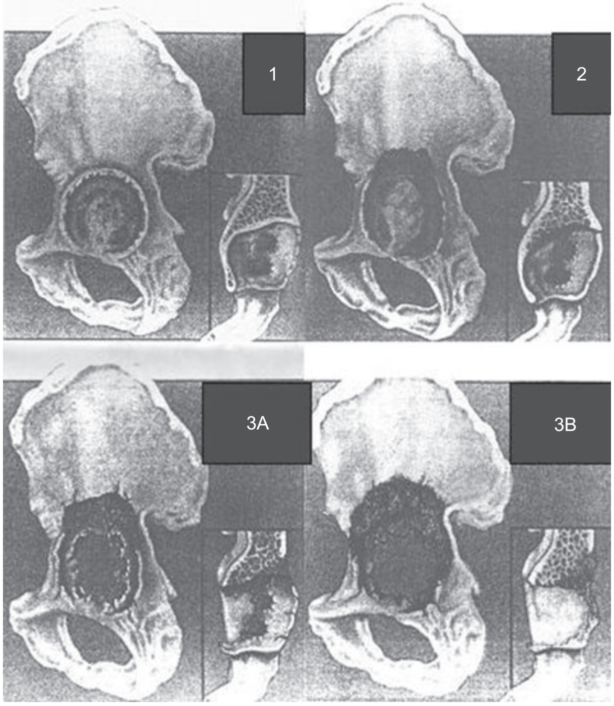

Figure 1 Paprosky defect classifications of the human hip joint [17].

The foam blocks with the implanted cups were fixed to a ball bearing-mounted plate in an angle of 29° to the horizontal base plate of the measurement station (MTS® 407, Tailored Test Solutions, Worthing, UK; Figure 2) to collect the micromotion (Figure 3). The transmission force was exerted on the cup in the same way as it would on an endoprosthesis implanted in the human body at a 45° inclination. This coherence results from Pauwels' hip model, with a deviation of 16° centrally to the vertical plane [18]. The prostheses once inserted were exposed to a load with a cyclical, sinusoidal force of a frequency of 1 Hz, representing the standard walking speed. The force was exerted on the cup through an appropriate prosthesis shaft and head with a diameter of 28 mm and according to Bergmann's values of the exposure of a normal motion of a patient of 90 kg (198 lb), which yields a maximum of 3800 N and an initial load of 300 N [2]. This preload simulates the force of the head of the femur on the

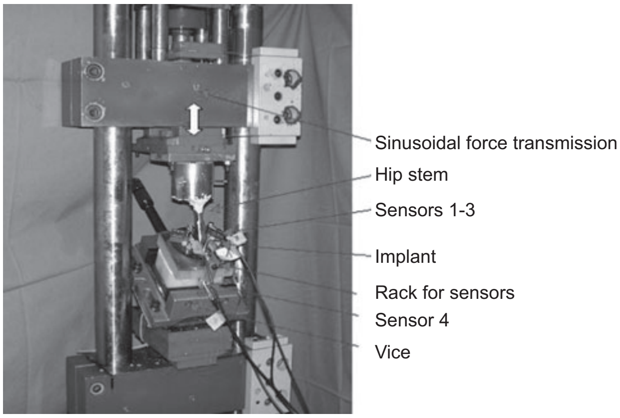

Figure 2 Measurement station (MTS 407, Tailored Test Solutions, Worthing, UK) for testing micromotions.

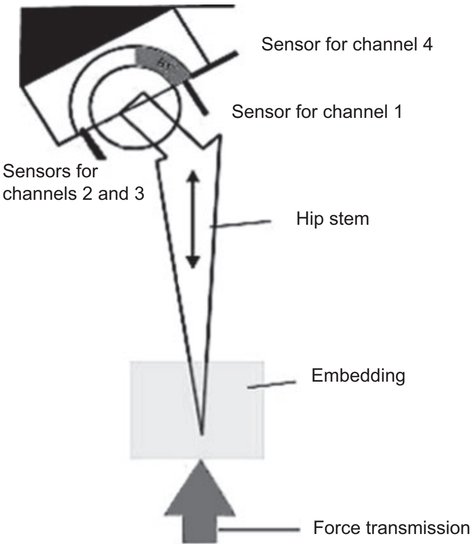

Figure 3 Schematic arrangement of the measurement of micromotions.

acetabulum by muscle contraction in a quiescent condition with decompression of the joint.

The micromotions, which are the movements between the implant and implant bearing, were recorded by four sensors (Induktive Economic-Wegtaster WETA 1/2 mm, Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany). These sensors were fixed in a rack that was screwed to the implant bearing with four screws, with a maximum distance of 3 mm from the implant. The detector heads were placed on the rim of the implant. This ensured that the relative movements between the implant bearing and the implant were almost the only movements recorded. The elastic deformation of the implant bearing was almost completely excluded, with a systematic error of <5%.

Three of the sensors were placed vertically to the plane of the acetabulum, each one rotated by 120°. The position of the sensors are at points representative of:

- the cranial acetabular rim (sensor 1);
- the teardrop (sensor 2); and
- the dorsal acetabular rim (sensor 3).

Sensor 4 was installed at the cranial edge of the implant, vertical to sensor, parallel to the plane of the rim.

The values extracted were recorded by a computer (Apple Power Macintosh 6100/66) and a corresponding measuring program (Beam Version 3.1, Gesellschaft für angewandte Mess- und Systemtechnik mbH, Chemnitz, Germany). The measuring procedure lasted for 150 s; the data measured were read off at five consecutive measuring amplitudes after 120–125 measuring seconds. An average value for each channel was then calculated.

Each implant was run through the measuring cycle five times for each type of defect. From the extracted values, an average value was derived for each implant and each type of defect. From the average values of all the implants, an average value was derived according to the exterior forms for conical/parabolic and spherical exterior forms. These values were then analysed for statistical significance using the 95% confidence interval.

Results

With Paprosky defect type 0 (Table 2), in the primary implantation, only the Lamella implant (Zimmer Inc., Australia), showed micromotion values of over 200 µm on one channel. The conical/parabolic threaded implants showed higher micromotions than the spherical threaded implants, with a significant difference on channel 1.

With Paprosky defect type 1 (Table 3), a slight increase in the micromotions was detected in comparison to the primary implantation, especially on channel 4; however, the critical value of 200 µm was not exceeded. Distinguishing between spherical and conical/parabolic exterior forms, the implants with conical/parabolic forms showed a clear increase in micromotions with a significant difference on channel 2.

Table 2 Micromotions of the threaded implants tested in rigid foam blocks for primary acetabuli without defects.

Implant	Micromotions in µm			
	Channel 1	Channel 2	Channel 3	Channel 4
Aesculap SC	108.2	88.2	87.0	92.1
Lamella	98.4	165.2	218.6	71.4
MUC II	85.2	70.8	50.9	63.1
Ultima	121.4	101.2	99.8	40.2
Zintra	91.6	57.8	78.4	35.2
Average of spherical implants	*101.0*	*96.6*	*106.9*	*60.4*
Alloclassic	129.1	107.8	54.1	87.6
Bicon	132.8	134.4	102.1	79.6
Hofer Imhof	154.4	84.4	136.3	118.4
Variall	121.6	155.6	147.3	65.1
Average of conical implants	*134.5*	*120.6*	*110.0*	*87.7*
Average of all implants	***115.9***	***107.3***	***108.3***	***72.5***

Italic highlights the averages of the different shapes, bold highlights the overall average.

Table 3 Micromotions of the threaded implants tested in rigid foam blocks for a Paprosky type 1 defect.

Implant	Micromotions in µm			
	Channel 1	Channel 2	Channel 3	Channel 4
Aesculap SC	108.7	117.2	123.3	72.2
Lamella	99.8	95.0	121.5	183.6
MUC II	113.9	87.9	53.2	107.6
Ultima	118.6	84.0	106.3	77.0
Zintra	90.2	84.7	87.4	54.2
Average of spherical implants	*106.2*	*93.8*	*98.3*	*98.9*
Alloclassic	133.8	95.5	99.0	59.8
Bicon	109.4	184.3	144.0	139.0
Hofer Imhof	138.1	180.2	173.5	83.1
Variall	124.5	163.1	189.8	90.4
Average of conical implants	*126.5*	*155.8*	*151.6*	*93.1*
Average of all implants	***115.2***	***121.3***	***122.0***	***96.3***

Italic highlights the averages of the different shapes, bold highlights the overall average.

The micromotions of the conical threaded implants with Paprosky defect type 2 (Table 4) showed higher values than the spherical threaded implants. The Hofer-Imhof implant exceeded the critical value of 200 µm on channels 1 and 3.

There were two type 3 defects tested. The micromotions of the threaded implants with Paprosky defect type 3a (Table 5) increased noticeably on all channels compared to defect type 2. The critical value of 200 µm was exceeded by Zintra

Table 4 Micromotions of the threaded implants tested in rigid foam blocks for Paprosky defect type 2.

Implant	Micromotions in µm			
	Channel 1	Channel 2	Channel 3	Channel 4
Aesculap SC	135.3	112.7	134.1	73.6
Lamella	136.9	117.7	168.9	71.8
MUC II	111.8	68.8	83.7	59.3
Ultima	133.3	90.3	114.8	137.5
Zintra	135.9	100.5	124.7	90.6
Average of spherical implants	*150.3*	*95.3*	*117.0*	*83.5*
Allo Classic	118.1	96.6	91.4	144.0
Bicon	204.4	154.5	220.4	103.1
Hofer Imhof	153.8	117.0	111.5	124.9
Variall	162.3	112.8	122.2	110.7
Average of conical implants	*156.7*	*115.9*	*135.1*	*113.9*
Average of all implants	***145.1***	***107.3***	***129.3***	***100.9***

Italic highlights the averages of the different shapes, bold highlights the overall average.

Table 5 Micromotions of the threaded implants tested in rigid foam blocks for Paprosky defect type 3a.

Implant	Micromotions in µm			
	Channel 1	Channel 2	Channel 3	Channel 4
Aesculap SC	178.3	179.3	194.6	148.3
Lamella	144.0	126.0	104.0	124.8
MUC II	166.6	134.5	173.8	104.2
Ultima	155.7	202.0	213.5	97.3
Zintra	248.7	130.3	140.1	143.8
Average of spherical implants	*178.7*	*154.4*	*165.2*	*123.7*
Allo Classic	223.5	124.2	148.6	130.6
Bicon	150.8	196.6	134.1	139.0
Hofer Imhof	134.0	122.0	106.3	144.2
Variall	137.6	174.2	168.7	155.3
Average of conical implants	*161.5*	*154.3*	*139.4*	*142.3*
Average of all implants	***171.0***	***154.3***	***153.7***	***131.9***

Italic highlights the averages of the different shapes, bold highlights the overall average.

Table 6 Literature overview of studies on the micromotions of press-fit implants.

Authors	Force	Model	Micromotions
Pitto et al. 2001 [21]	2354 N	Polyurethane pelvis	Average value: 115 μm Maximum: 146 μm
Pitto et al. 1997 [20]	2354 N	Plastic pelvis	Average value: Without screws: 35–153 μm With screws: 82–266 μm
Won et al. 1995 [28]	1500 N	Human bone, frozen flesh	Average value: 10–51 μm Maximum: 180 μm
Perona et al. 1992 [19]	2354 N	Human bone preserved in formalin	162 μm measured at the os ilium
Stiehl et al. 1991 [24]	1000 N	Human bone preserved in formalin	Cyclical: <125 μm Static: >150 μm

(NV, USA; channel 1), Alloclassic (Zimmer Inc., Australia; channel 1), and Ultima (DePuy, USA; channels 2 and 3). There was no significant difference between spherical and conical/parabolic threaded implants. The implants could not be appropriately inserted in samples with Paprosky defect type 3b because of an insufficient supply of acetabular rim.

Discussion

The long-term clinical performance of threaded hip endoprostheses have improved since the second generation has been with equipped with a porous coated surface [10, 29]. Even though the high revision rates of first-generation cups with a smooth surface have caused those cups to be abandoned in the Anglo-American area, the second-generation cups have similar long-term survival rates to press-fit cups. [3, 5, 6].

As primary stability is the key element to good long-term results following hip endoprosthesis, Schwarz et al. have analysed the torque-in and lever-out-moments of threaded acetabular cups displaying factors for measurement of the primary stability [23]. The micromotions between implant and implant bearing are a risk factor and are signs of loosening of the prosthesis material. The micromotions of press-fit implants have already been experimentally studied in numerous ways (Table 6). To our knowledge, no current studies of this kind exist for threaded implants. Some studies have examined the micromotions of endoprosthetic material; Cristofolini et al. examined the femoral shaft component [4], Hsu and Won emphasised the value of micromotions in examining the necessity of additional screw fixation of the acetabular component [11, 28], and Amirouche et al. analysed the micromotions between liner and acetabular shell during subluxation/relocation mechanisms [1].

Pitto defined 200 μm as the critical barrier for micromotions, because from this point onwards, osteointegration will be disrupted [21]. This limit was only exceeded in one channel in defect type 0 by the Lamella implant. It was not exceeded by any implants in defect type 1. In defect type 2, only the Bicon implant showed a value of more than 200 μm in two of the four sensors. In defect type 3a, the Ultima, Zintra and the Alloclassic implants exceeded this level of disturbed osteointegration.

Polyvinylchloride foam was used as a bone substitute in previous studies [7, 8, 12, 23]. These materials have the advantage of a homogeneous structure in comparison to the heterogeneity of human bone. Palissery et al. [15] have analysed Herex C70 and have found several similarities with human bone, but the tensile properties of the foam were greater than in compression, which the opposite of the mechanical behaviour of cancellous bone. Those studies show that the complexity and biomechanical diversity of human bone are yet to be fully discovered and are hard to simulate using industrial materials. Even though this reduces the comparability of the results to the *in vivo* situation, polymer foams are an established bone surrogate and a good way to achieve a reproducible result.

The values published to date for micromotions of press-fit implants range within the scope of the following values (see Table 6).

Considering the exterior form of the threaded implants, no significant difference in primary stability can be detected between spherical and conical/parabolic implants. The spherical implants, however, displayed a tendency towards lower values for micromotions and therefore a higher primary stability. With defect type 3a according to Paprosky, the value changed. Here the conical/parabolic implants showed lower values. This could be related to the distributed strains that act upon the whole exterior wall of the acetabulum [25]. In contrast, with the spherical implants the strains are concentrated on the edges of the exterior wall with the maximum diameter [26]. Furthermore, the deeper milling of the conical/parabolic implants could have a role in producing these lower values. This deeper milling means that more bone material is lost. In addition, the position of the conical/parabolic implants is determined by the milling and cannot be changed in relation to anteversion.

In summary, it can be said that all of the implants tested are suitable for implantation but it must be noted that there is an increase in micromotions and therefore a higher risk of loosening of the prosthesis with higher defect types. With Paprosky defect type 3b, an implantation without reconstructive measures is no longer recommended.

References

[1] Amirouche F, Romero F, Gonzalez M, Aram L. Study of micromotion in modular acetabular components during gait and subluxation: a finite element investigation. J Biomech Eng 2008; 130: 021002.

[2] Bergmann G, Graichen F, Rohlmann A. Hip joint forces during walking and running, measured in two patients. J Biomech 1993; 26: 969–990.

[3] Blaschke H, Kiss H, Dohnalek C, Abdolvahab F, Effenberger H, Dorn U. Langzeitergebnisse der Hofer-Imhof Pfanne. In Dorn U.: 10 Jahre Hofer-Imhof Pfanne. Kompendium des Symposiums vom 25.04.1998 in Salzburg: 31–41.

[4] Cristofolini L, Varini E, Viceconti M. In-vitro method for assessing femoral implant-bone micromotions in resurfacing hip implants under different loading conditions. Proc Inst Mech Eng H 2007; 221: 943–950.

[5] Delaunay CP, Kapandji AI. Survivorship of rough-surfaced threaded acetabular cups. 382 consecutive primary Zweymuller cups followed for 0.2–12 years. Acta Orthop Scand 1998; 69: 379–383.

[6] Effenberger H, Böhm G, Huber M, Lintner F, Hofer H. Experimental study of bone-implant contact with a parabolic acetabular component (Hofer-Imhof). Arch Orthop Trauma Surg 2000; 120: 160–165.

[7] Effenberger H, Schwarz M, Witzel U. Der Einfluss der Gewindeform auf das Eindrehverhalten von Schraubpfannen. Orthopädische Praxis 2003; 39: 378–385.

[8] Favard, L, Bonnard C, Burdin P, Rosset P, Bertrand P, Queguiner A. Experimental study of the primary fixation of screw-ring acetabular components. Rev Chir Orthop Reparatrice Appar Mot 1992; 78: 223–227. [In French].

[9] Fink B, Protzen M, Hansen-Algenstaedt N, Berger J, Rüther W. High migration rate of two types of threaded acetabular cups. Arch Orthop Trauma Surg 2004;124: 17–25.

[10] Havelin LI, Vollset, SE, Engesaeter LB. Revision for aseptic loosening of uncemented cups in 4,352 primary total hip prostheses. A report from the Norwegian Arthroplasty Register. Acta Orthop Scand 1995; 66: 494–500.

[11] Hsu JT, Lai KA, Chen Q, et al. The relation between micromotion and screw fixation in acetabular cup. Comput Methods Programs Biomed 2006; 84: 34–41.

[12] Klanke J, Hörmannsdörfer G, Westermann K. Quality criterias of threaded cups determined by a new screw-in experimental setup, Hand out, SICOT, Poster Presentation, Sydney, 1999.

[13] Kody MH, Kabo JM, Markolf KL, Dorey FJ, Amstutz HC. Strength of initial mechanical fixation of screw ring acetabular components. Clin Orthop 1990; 257: 146–153.

[14] Litsky AS, Pophal SG. Initial mechanical stability of acetabular prostheses. Orthopedics 1994; 17: 53–57.

[15] Palissery V, Taylor M, Browne M. Fatigue characterization of a polymer foam to use as a cancellous bone analog material in the assessment of orthopaedic devices. J Mater Sci Mater Med 2004; 15: 61–67.

[16] Paprosky WG, Perona PG, Lawrence JM. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. J Arthroplasty 1994; 9: 33–44.

[17] Paprosky WG, Perona PG, Lawrence JM. Acetabular defect classification and surgical reconstruction in revision arthroplasty. A 6-year follow-up evaluation. J Arthroplasty 1994; 9: 33–44.

[18] Pauwels F. Atlas zur Biomechanik der gesunden und kranken Hüfte. Ed. 1 Berlin, Heidelberg, New York, Springer Verlag, 1973.

[19] Perona, PG, Lawrence J, Paprosky WG, Patwardhan AG, Sartori M. Acetabular micromotion as a measure of initial implant stability in primary hip arthroplasty. An in vitro comparison of different methods of initial acetabular component fixation. J Arthroplasty 1992; 7: 537–547.

[20] Pitto RP, Bohner J, Hofmeister V. Factors affecting the primary stability of acetabular components. An in vitro study. Biomed Tech (Berl) 1997; 42: 363–368. [In German].

[21] Pitto RP, Willmann G, Schramm M. Initial stability of modular acetabular components. Comparative in-vitro study with polyethylene and ceramic liners. Biomed Tech (Berl) 2001; 46: 109–112.

[22] Schneider E, Kinast C, Eulenberger J, Wyder D, Eskilsson G, Perren, SM. A comparative study of the initial stability of cementless hip prosthesis. Clin Orthop 1989; 248: 200–209.

[23] Schwarz ML, Scheller G, Effenberger H. Primary stability of threaded cups in THR–an experimental study. Biomed Tech (Berl) 2003; 48: 334–338.

[24] Stiehl JB, MacMillan E, Skrade DA. Mechanical stability of porous-coated acetabular components in total hip arthroplasty. J Arthroplasty 1991; 6: 295–300.

[25] Ungethüm M, Blömer W. Biomechanische Aspekte zementfreier Hüftpfanne-implantate mit Schraubverankerung. Med Orthop Techn 1986; 6: 194–197.

[26] Ungethüm M, Blömer W. Überlegungen zum Pfannendesign. Sphärisch oder konisch? Gewinde selbstschneidend oder geschnitten? In: Hipp E, Gradinger R, Ascherl R. (Hrsg.) Die zementlose Hüftprothese. Demeter, Gräfeling 1992: 137–142.

[27] Reprinted from von Schulze Pellengahr C, Bürkner A, Plitz W, et al. Macerated human hip bone preparation as a substitute for fresh frozen preparations for testing the primary stability and frictional torques of cementless hip cups. Z Orthop Ihre Grenzgeb 2005; 143: 638–44. [In German].

[28] Won CH, Hearn TC, Tile M. Micromotion of cementless hemispherical acetabular components. Does press-fit need adjunctive screw fixation? J Bone Joint Surg Br 1995; 77: 484–489.

[29] Yahiro MA, Gantenberg JB, Nelson R, Lu HT, Mishra NK. Comparison of the results of cemented, porous-ingrowth, and threaded acetabular cup fixation. A meta-analysis of the orthopaedic literature. J Arthroplasty 1995; 10: 339–350.

Received February 26, 2012; accepted May 3, 2012; online first May 31, 2012