Long-term survival of the uncemented Balgrist total hip replacement cup

Jiri Gallo · Jiri Lostak · Katerina Langova

Received: 6 March 2013 / Accepted: 15 May 2013 / Published online: 8 June 2013
© Springer-Verlag Berlin Heidelberg 2013

Abstract

Purpose The purpose of this study was to evaluate the long-term clinical and radiographic outcomes of the Balgrist total hip replacement cup.

Methods We report the results of a retrospective review of 195 total hip prostheses with Balgrist cup implanted in 178 patients. There were 59 men and 119 women with a mean age at surgery of 52.3 years (range, 19–72). Cox regression was used to determine the influence of independent variables on the survivorship of the prosthesis.

Results There were 117 (66 %) of 178 patients, and 131 (67 %) of 195 hips available for assessment at a mean follow-up of 17.4 years. A total of 21 patients (22 hips) were lost from follow-up (12 %). A total of 25 patients (27 hips) required some type of re-operation during the follow-up period. Eight of 27 re-operations (30 %) were directly caused by the Balgrist cup failure due to fatigue fracture of the metallic shell ($n=5$; 19 %), polyethylene wear ($n=2$; 7 %) and aseptic loosening ($n=1$; 4 %). The mean polyethylene wear rate was 0.068 mm/year (range, 0.008–0.230; SD=0.043). The risk of re-operation for any reason was decreased with dysplastic hip as a primary diagnosis (hazard ratio; HR=0.250; 95 % CI 0.086–0.725) and with greater age at the time of surgery (HR=0.923; 95 % CI 0.880–0.969). The 19-year survivorship with re-operation for any reason was 75.6 % (95 % CI 67.0–84.2). The 19-year survivorship with re-operation for the Balgrist cup failure was 90.5 % (95 % CI 83.4–97.6).

Conclusions The Balgrist cup continues to provide excellent clinical and radiological outcomes. This is associated at least in part with a low polyethylene wear rate. The main reason for the Balgrist cup failure is fatigue fracture of the metallic shell.

Introduction

Despite the proven effectiveness of total hip arthroplasty (THA) in relieving hip osteoarthritis pain, THA outcomes have come under intense public scrutiny in recent years [1]. The reason is simple—not all THA implants function without problems for sufficiently long time period and not all patients can benefit from THA surgery [2]. To answer the question on long-term behaviour of THA implants several THA registries have been established in many countries. In addition, there is a growing need to study other data and especially the reasons for revision. According to a large number of studies including those derived from national replacement registries and meta-analyses [3–8], the cup seems to be the weakest link of THA with aseptic loosening and polyethylene wear-related complications being the most frequent indications for revision of primary THA. The reported results of cemented and uncemented cups are difficult to compare directly and even comparisons between uncemented cups are not possible without detailed knowledge of at least the design and material characteristics of the compared implants [3, 9]. Poor survival of early generations of uncemented cups was related in part to design errors together with a problem of polyethylene quality [10–13].

Schreiber et al. designed the Balgrist cup in early 1980s and it was introduced in clinical practice in 1982 [14]. Several studies demonstrated good survival to date [15, 16]. The primary aim of the study was to evaluate the long-term clinical and radiographic outcomes of the uncemented Balgrist cup used as a part of primary THA in a consecutive cohort of patients. Currently, this cup is not in use; however, the polyethylene Sulene implanted into the

J. Gallo (✉) · J. Lostak
Department of Orthopaedics, Faculty of Medicine and Dentistry,
Palacky University Olomouc, University Hospital, I. P. Pavlova 6,
77520, Olomouc, Czech Republic
e-mail: jiri.gallo@volny.cz

K. Langova
Department of Medical Biophysics, Faculty of Medicine
and Dentistry, Palacky University, Hněvotinská 3,
775 15, Olomouc, Czech Republic

Balgrist cup is still in clinical use. Secondly, we aimed to assess whether there is any association between the re-operation of the THA with Balgrist cup and a set of patient-, surgery-, and implant-related factors. Thirdly, we believe that a report on the long-term outcomes related to a particular uncemented THA could contribute to a current discussion on which fixation for THA [3, 17].

Patients and methods

Patients

A total of 195 primary THAs using Balgrist cups were performed in 178 consecutive patients between June 1993 and December 1995. Of these, 59 (33 %) were performed in men and 119 (67 %) in women. Their mean age at surgery was 52.3 years (range, 19–71.7). We invited all of these patients to be clinically and radiographically examined between September 2011 and June 2012. At the latest follow-up 64 hips (33 %) in 61 patients could not be checked because they had died from causes unrelated to their THA ($n=40$ patients; 22 %) or could not be contacted or refused the clinical examination ($n=21$ patients; 12 %; Fig. 1). The ethics committee of the institution approved the study protocol and all re-operations were performed with the written informed consent of the patients.

Implant

The Balgrist cup consists of two tapered parts: an expansive outer titanium-alloy splitting the ring and achieving firm press-fit fixation (Fig. 2), and a self-locking metal-backed inlay made of Sulene polyethylene [14]. The outer metallic part was made of Protasul™-Ti with roughened surface supporting bone-ongrowth (Fig. 3). Overall, six sizes of the cup were available (range, 47–64 mm). Sulene was a calcium stearate-free ultra high molecular weight polyethylene, compression molded and machined. Components were

gamma irradiation sterilized under nitrogen gas atmosphere. In most cases the Balgrist cup was implanted either with cemented Weber-Stuhmer stem (78 hips; 59.5 %) or with uncemented Alloclassic Zweymuller stem (47 hips; 35.9 %). A 28-mm Al_2O_3 ceramic head was articulated against the Sulene polyethylene in the majority of cases (128 hips; 97.7 %). Inclusion data related to patients and implants are showed in Table 1.

Patients were protected from weight bearing with crutches for the first eight weeks, which was followed by a period of partial weight bearing as tolerated and full loading was permitted 12 weeks after the surgery. All patients had routine peri-operative antibiotics and prophylaxis against thromboembolic disease using subcutaneous heparin for 12 days followed by aspirin or warfarin.

Clinical and radiographic examination

Patients were assessed clinically and radiographically three, six and 12 months postoperatively, and then irregularly depending on their complaints. All the hips included in the study had a stable prosthesis one year after the index surgery based on review of radiology reports. A clinical researcher (JL) who was not involved in the patient's index surgery performed the last assessment. Clinical examination consisted of range of motion measurement of the hip joint, measurement of leg-length, and manual muscle testing of muscle power. In addition, we collected patient-reported evaluations of satisfaction with a hip, their estimation of walking distance, and data on walking aids. Finally, we calculated the Harris Hip score [18] and determined University of California, Los Angeles (UCLA) activity scale [19]. The Charnley classification was applied to estimate the level of walking capacity [20].

Anteroposterior pelvic radiographs were performed with the patient in the supine (non-weight-bearing) position. Interpretation of radiographs consisted of the evaluation of the cup/ stem stability, cup position in regard to the lateral part of tear drop figure, determination of the cup position relative to the true acetabular region [21] and measurement of the abduction angle of the cup. Aseptic loosening of the cup and stem was evaluated using a method described elsewhere [22, 23]. Acetabular radiolucent lines location was described using the method of DeLee and Charnley [24]. Femoral radiolucent lines location was described using the method of Gruen [25]. The position of the cup in relation to the floor of acetabulum was graded as lateral, in contact, or medial depending on relationship between a most medial part of the cup and Kohler's line [26]. The abduction angle is the angle formed by a horizontal line along the teardrops, ischial tuberosities or obturator foramina and a line along the open face of the cup. The extent of polyethylene wear was measured according to the technique described by Dorr et al. on digital imaging [27].

Fig. 1 Patient cohort

Fig. 2 **a.** The Balgrist cup with polyethylene liner involved (courtesy of P. Kaminek, MD, PhD). **b.** Principle of the Balgrist cup expansion into a bone bed (like a “dowel”) (courtesy of P. Kaminek, MD, PhD). **c.** Reconstruction of a dysplastic hip using the Balgrist cup and a bulk graft (courtesy of P. Kaminek, MD, PhD)

Statistics

The primary goal of the study was to determine the survivorship of the Balgrist cup. Survival of the index prosthesis was computed using the Kaplan-Meier analysis. To determine the influence of loss to follow-up on the survivorship data of the Balgrist cup we assumed that all these patients had re-operations of their hips to the time of last follow-up [28].

The Shapiro-Wilk's test was used to determine whether the numerical data set is well modeled by a normal distribution. Student's t-test was applied on data with a normal distribution while Mann-Whitney U-test and Wilcoxon test were used in the remaining ones. For analysing categorical data we used Fisher's exact test. Then the Cox proportional-hazards regression was applied to determine the effect of several independent variables on the risk of re-operation as the event. Regarding the primary diagnosis, primary osteoarthritis was set up as a reference category with other diagnoses (i.e. dysplastic, traumatic and inflammatory) being related to it. According to wear rate hips were divided into those having wear rate above 0.1 mm/year and those below. Statistical significance was set at p -value < 0.05. Statistical analysis was performed with the commercial SPSS 15.0 package (SPSS Inc., Chicago, IL, USA).

Results

Clinical outcomes

During the study period 27 hips (20.6 %) in 25 patients underwent revision surgery. The most frequent single reason for the Balgrist cup re-operation was fracture of the cup ($n=5$; 18.5 %; Table 2; Fig. 4). Median time to re-operation due to fracture of the cup was 14.9 years (95 % CI 11.146–18.656).

At the time of the last examination 98 patients (94.2 %) were satisfied with the physical state of their hip and overall function. However, six patients were dissatisfied (5.8 %). The median of Harris hip score increased from 41 points (range, 4–85) pre-operatively to 85 points (range, 40–100) at final follow-up (Wilcoxon; $p < 0.0001$). Walking distance of three kilometres or more was reported by 28 of reviewed patients (30.5 %) and 36 patients (39.1 %) determined their walking capacity between one and three kilometres. In contrast, ten patients (10.9 %) declared they were unable to walk 500 metres. Twenty-two

patients (23.9 %) were strongly dependent on walking aids while 41 patients (44.6 %) used them from time to time.

Fig. 3 **a.** Top view on an anchorage part of the Balgrist cup **b.** Side view on an anchorage part of the Balgrist cup. **c.** Top view on the complete Balgrist cup with a retrieved (after 16.5 years) polyethylene liner involved

Fifty-eight patients (63.0 %) reported UCLA activity score between 4 and 7 and 29 patients (31.5 %) between 1 and 3.

Strength of the abductors of the hip was rated as good in 76 hips (73.1 %), weak in 22 hips (21.2 %), and poor in six hips (5.8 %). Leg-length measurement revealed discrepancy less than or equal to 1.0 cm in 74 limbs (80.4 %) while in the remaining patients the difference was greater than 1.0 cm. Comparing the changes in the Charnley classification pre-operatively and at the last follow-up, we found a significant decrease in the number of A-type patients (McNemar test; $p = 0.0002$). Finally, our patients increased their weight during the time of follow-up from a mean of 72 (range, 50–102) to 75.9 (56–120) kg (Wilcoxon; $p < 0.0001$).

Table 1 Pre-operative and surgery-related data for the group of patients/ hips with a known fate (i.e. revision-free and re-operated)

Variable	Data ($n = 117$ patients/131 hips)
Age at surgery; years	51.1 (19–71.7; SD 8.9) ^a
Sex; M/W	32/85 (27 %/73 %)
Height (cm)	165.6 (148–184; SD 7.4)
Weight (kg)	71.9 (50–102; SD 11.1)
BMI	26.2 (17.7–34.8; SD 3.4)
Type of patient (Charnley)	
A	44 (37.6 %)
B	62 (53.0 %)
C	11 (9.4 %)
Primary diagnosis	
Primary osteoarthritis	35 (26.7 %)
Trauma	16 (12.2 %)
Dysplastic hip	74 (56.5 %)
Inflammatory hip	6 (4.6 %)
Preoperative HHS	41 (4–85; IQR 38–48) ^b
Size of the cup (mm)	50 (47–64; IQR 50–53)
Inclination angle (°)	46.2 (24–78; SD 9.0)
Cup relation to KL	
Laterally	41 (31.3 %)
In contact	49 (37.4 %)
Medially	41 (31.3 %)
Cup relation to TAR	
Placed in TAR	56 (42.7 %)
Slightly above	52 (39.7 %)
HHC	23 (17.6 %)

HHC high hip center, *HHS* Harris hip score, *KL* Köhler line, *TAR* true acetabular region, *SD* standard deviation, *IQR* interquartile range

^a Mean (minimum-maximum)

^b Median (minimum-maximum)

Table 2 Shows all reasons for revision in our group of THAs with the Balgrist cup; *wt*-without

Reason for revision	Data ($n = 27$)
Aseptic loosening of the stem	5 (18.5 %)
Fracture of the cup	5 (18.5 %)
Fracture of the femur	4 (14.8 %)
Heterotopic ossification	3 (11.1 %)
Painful THA wt any reason	3 (11.1 %)
Dislocation	2 (7.4 %)
Deep sepsis	2 (7.4 %)
Wear of polyethylene	2 (7.4 %)
Aseptic loosening of the cup	1 (3.7 %)

Fig. 4 A 75-year-old woman with bilateral THA; anteroposterior X-ray of the fractured Balgrist cup reoperated 17.5 years after the index surgery; osteolysis is present around the stem

Radiographic outcomes

Of the surviving original THAs, 78 (75.0 %) had stable cup without radiolucency and/or osteolysis while 24 hips (23.0 %) had stable cup but with radiolucent lines in at least one DeLee-Charnley zone. In addition, one hip showed signs of aseptic loosening (1.0 %) and one hip demonstrated fracture of metallic shell of the cup (1.0 %).

Regarding the stem evaluation, 75 THAs (72.1 %) had a stable stem without radiolucency or osteolysis while 25 THAs (24.0 %) had radiolucent lines crossing at least three zones according to Gruen topology and four hips (3.8 %) showed signs of radiographic stem loosening. The mean polyethylene wear rate was 0.068 mm/year (range, 0.008–0.230; SD=0.043).

Survivorship analysis

At a mean follow-up of 17.4 years (95 % CI 16.7–18.2), we obtained complete clinical and radiographic follow-up in 67.2 % of all originally implanted hips. The 19-year survivorship of evaluated hips with re-operation for any reason was 75.6 % (95 % CI 67.0–84.2; Fig. 5a). The 19-year survivorship with only re-operation for Balgrist cup failure was 90.5 % (95 % CI 83.4–97.6; Fig. 5b). When radiographic loosening was included the 19-year survivorship of Balgrist cup was 88.0 % (95 % CI 80.4–95.6; Fig. 5c). Survival analyses are illustrated in Table 3 including those related to loss to follow-up.

Multivariable Cox regression analysis was performed for age, gender, height, weight, primary diagnosis, and size of the cup. We identified older age at the time of surgery (HR=hazard ratio=0.923; 95 % CI 0.880–0.969; $p=0.001$) and patients undergoing THA for osteoarthritis secondary to hip dysplasia (HR=0.250; 95 % CI 0.086–0.725; $p=0.011$) as being independently associated with a decreased risk of re-operation.

Fig. 5 **a** Survivorship curve with the end point of revision for any reason (details see in Table 2). **b** Survivorship curve with the end point of only reoperation of the Balgrist cup. **c** Survivorship curve with the end point of re-operation and radiographic failure of the Balgrist cup

Discussion

There is relative paucity of studies in the literature reporting the long-term outcomes of uncemented acetabular components. We found good clinical and radiographic long-term outcomes for the uncemented Balgrist cup. The most frequent single pattern of its clinical and radiographic failure was fracture of a metallic shell (Fig. 4), with aseptic loosening of the Balgrist cup being observed in only two hips.

The 19-year survivorship of the Balgrist cup with clinical and radiographic failure as the endpoint was 88 % in the present study, which is comparable with the best uncemented

Table 3 Life tables calculated with the following end-points: re-operation for any reason, reoperation due to Balgrist cup failure, re-operation of Balgrist cup and radiographic failure (fracture, aseptic loosening)

Time (years)	Cumulative proportion surviving at the time	95% CI	
Any reason			
10	0.893	0.840	0.946
15	0.854	0.793	0.915
19	0.756	0.670	0.842
19 ^a	0.455	0.326	0.584
Balgrist cup re-operation			
10	0.992	0.976	1.000
15	0.966	0.933	0.999
19	0.905	0.834	0.976
19 ^a	0.529	0.384	0.674
Balgrist cup re-operation+ radiographic failure			
10	0.992	0.976	1.000
15	0.966	0.933	0.999
19	0.880	0.804	0.956
19 ^a	0.517	0.374	0.660

^a The worst-case scenario assuming all lost-to-follow-up patients had their hip re-operated at the time of last follow-up

implants having a minimum 17-year survivorship [29–31]. However, comparison of implants according to their fixation principles (cemented, hybrid, uncemented) is difficult assuming, for instance, differences in materials, constructions, patients and their life-styles as well as among surgeons. Corten et al. recently published the last report from a randomized controlled trial [32, 33] investigating the question of the superiority of cemented over uncemented primary THA [34]. They revealed lower survival rates of cemented compared with uncemented THA at 20 years after surgery performed by experienced surgeons. However, they did not compare classical cemented polyethylene cups but non-modular so-called metal-backed cup. In this line, neither a recent literature search nor a systematic review shows clear superiority of uncemented cups in terms of survival over the cemented cups [3, 17]. Hence, some authors have concluded that cemented polyethylene cups remain the gold standard in all age groups until uncemented cups have been demonstrated to be superior [3]. As a result, Pakvis et al. recommended an orthopaedic surgeon should choose cemented or uncemented socket for hip replacement based on patient characteristics and his/her knowledge, experience and preference [17].

The main problem of the Balgrist cup in the present study was a fracture of the metallic shell (five already re-operated and five waiting for re-operation), which may be causally linked to the weakening of the bone support (e.g. by osteolysis, fatigue fracture behind a cup). Some role could play a specific design of the cup (“like a dowel”) with the

thin transverse stripes interconnecting several relatively robust perpendicularly oriented lamellae of the metallic shell (Fig. 3). Under such conditions, an excessive strain in a titanium split ring could overcome the firmness of the material leading eventually to a fracture at the site of the transverse stripes. Echtler et al. had to re-operate on seven hips due to implant breakage [15]. Surprisingly, the mean time to implant fracture was 55 months in their study, which does not correspond with our experience (median to re-operation due to fracture was almost 15 years). Martín-Guinea et al. reported three cases (3 %) of Balgrist cup breakage in a study with a ten-year follow-up [35], while Ishaque et al. did not find any fractured Balgrist cup with a minimum of ten-year follow up [16]. Importantly, fracture of the similarly designed uncemented cups has been observed [31, 36]. Taken together, cups like Balgrist, Spotorno and others having a thin metallic shell are vulnerable to fracture in the long-term because they are probably not able to withstand chronic strains associated with a localized loss of bone support [37].

A major factor of aseptic loosening is particle disease that is triggered and perpetuated predominantly by particle load associated with wear of bearing surfaces and corrosion [38]. In this line, there is evidence that bearing surfaces strongly predict the fate of a THA [39, 40]. Very low rate of aseptic loosening observed in the present study could be associated at least in part with a low mean polyethylene wear rate. Importantly, this polyethylene is still in use and also other investigators report similar wear-rate data for the Balgrist cup [15, 35].

This study has demonstrated greater age and THA for osteoarthritis secondary to hip dysplasia, relative to primary osteoarthritis, are independently associated with a lower reoperation rate for uncemented Balgrist cup. Both of these can be related to a lower level of physical activities [41, 42]. The physical activity of the patient strongly affects the implant survival in terms of aseptic loosening and periprosthetic osteolysis in THA (thus the phrase “wear is a result of load and use”) [43]. Schmalzried et al. showed large inter-individual differences in daily activity, with the most active patient taking 3.2 million steps per year whereas the least active patient took only 72,000 steps per year [44]. However, a complex dysfunction of the hip secondary to dysplasia [45] does not disappear completely after THA surgery further preventing the patient with a dysplastic hip to achieve the same level of activity as a patient treated for primary osteoarthritis. On the other hand, we were unable to correlate causally the risk for revision and size of the cup postulating increased probability of polyethylene failure in the smaller cups. This could be explained by a low number of such revisions in our group of THAs.

Interestingly, we found an increase in the weight in our patients between the time of index surgery and the latest

follow-up pointing indirectly to the decrease in physical activity [42]. This may be interpreted such that some of the patients decrease their overall physical activity after THA surgery [46]. The leading explanation could be an increase in morbidity at other sites of weight-bearing joints. In this line, we found a decrease in the proportion of the type A patients according to Charnley classification at the latest follow-up in comparison to number of “A” patients at the time of index surgery. Despite that doubt has emerged concerning the validity of Charnley classification for evaluation of true physical level [47].

This study has limitations. First, this is a retrospective observational study [48]. Second, more than 10 % of patients were lost to follow-up. As a result, it can be assumed that these patients could have been re-operated elsewhere decreasing significantly the survivorship data reported here for the Balgrist cup (Table 3). This concern might be theoretically diminished by at least one study that reports that the patients who do not attend follow-up visits do not necessarily have poor results [49]. In addition, other authors argue that the outcome of the group lost to follow-up can be under some conditions close to the best-case scenario considering the method of worst-case scenario as an overestimation [28]. Finally, the end-points in survival analyses were re-operation and/or radiographic failure although some patients may not be satisfied with the outcome, and suffer from pain and walking problems earlier [2].

In summary, the Balgrist cup continues to provide excellent radiological and clinical outcomes at average 17.4 years postoperatively. Re-operations of the THA consisting of the Balgrist cup were done in a majority of cases from reasons other than aseptic loosening and/or osteolysis. Reported outcomes could be explained at least partially by excellent osseointegration of the titanium anchorage part of the cup, together with low polyethylene wear rate almost precluding aseptic loosening from a list of reasons for revision. On the other hand, this cup construction is prone to fracture, presumably from a deficient bone bed.

Acknowledgments The work on the study was supported by IGA Ministry of Health Czech Republic (IGA MZ CR NT/11049 and NT/14267). The authors thank Prof. Stuart B. Goodman from the Stanford Medical School for critical reading of the manuscript.

References

- Franklin PD, Allison JJ, Ayers DC (2012) Beyond joint implant registries: a patient-centered research consortium for comparative effectiveness in total joint replacement. *JAMA* 308:1217–1218
- Beswick AD, Wylde V, Gooberman-Hill R et al (2012) What proportion of patients report long-term pain after total hip or knee replacement for osteoarthritis? A systematic review of prospective studies in unselected patients. *BMJ Open* 2:e000435
- Clement ND, Biant LC, Breusch SJ (2012) Total hip arthroplasty: to cement or not to cement the acetabular socket? A critical review of the literature. *Arch Orthop Trauma Surg* 132:411–427
- Gallo J, Langova K, Havranek V et al (2008) Poor survival of ABG I hip prosthesis in younger patients. *Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub* 152:163–168
- Hailer NP, Garellick G, Karrholm J (2010) Uncemented and cemented primary total hip arthroplasty in the Swedish Hip Arthroplasty Register. *Acta Orthop* 81:34–41
- Makela KT, Eskelinen A, Pulkkinen P et al (2011) Results of 3,668 primary total hip replacements for primary osteoarthritis in patients under the age of 55 years. *Acta Orthop* 82:521–529
- Morshed S, Bozic KJ, Ries MD et al (2007) Comparison of cemented and uncemented fixation in total hip replacement: a meta-analysis. *Acta Orthop* 78:315–326
- Wroblewski BM, Siney PD, Fleming PA (2009) Charnley low-frictional torque arthroplasty: follow-up for 30 to 40 years. *J Bone Joint Surg Br* 91:447–450
- Van Der Veen HC, Van Jonbergen HP, Poolman RW et al (2013) Is there evidence for accelerated polyethylene wear in uncemented compared to cemented acetabular components? A systematic review of the literature. *Int Orthop* 37:9–14
- Harris WH (2009) The first 50 years of total hip arthroplasty: lessons learned. *Clin Orthop Relat Res* 467:28–31
- Pokorny D, Slouf M, Fulin P (2012) Current knowledge on the effect of technology and sterilization on the structure, properties and longevity of UHMWPE in total joint replacement. *Acta Chir Orthop Traumatol Cech* 79:213–221
- Rinnac C, Pruitt L, Implant Wear Symposium Engineering Work Group (2008) How do material properties influence wear and fracture mechanisms? *J Am Acad Orthop Surg* 16(Suppl 1):S94–S100
- Santavirta S, Goodman SB (2005) Total hip replacement: a successful interaction of biology, mechanics, and materials science. *Clin Orthop Relat Res* 430:2
- Jacob HA, Hilfiker B (1990) The self-locking Balgrist hip socket for cement-free fixation—history of its development and clinical experience to date. *Z Orthop Ihre Grenzgeb* 128:254–261
- Echtler B, Jacob HA, Houweling M et al (1999) 8-year survivorship analysis and subjective results of 687 primary Balgrist hip sockets. *Acta Orthop Belg* 65:346–356
- Ishaque BA, Basad E, Gils J et al (2009) Long-term results of the cementless conical Balgrist expansion cup—comparison analysis to the Zweymuller-Alloclassic screw cup. *Z Orthop Unfall* 147:707–715
- Pakvis D, Van Hellemond G, De Visser E et al (2011) Is there evidence for a superior method of socket fixation in hip arthroplasty? A systematic review. *Int Orthop* 35:1109–1118
- Harris WH (1969) Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. *J Bone Joint Surg Am* 51:737–755
- Zahiri CA, Schmalzried TP, Szuszczewicz ES et al (1998) Assessing activity in joint replacement patients. *J Arthroplast* 13:890–895
- Charnley J (1972) The long-term results of low-friction arthroplasty of the hip performed as a primary intervention. *J Bone Joint Surg Br* 54:61–76
- Pagnano W, Hanssen AD, Lewallen DG et al (1996) The effect of superior placement of the acetabular component on the rate of loosening after total hip arthroplasty. *J Bone Joint Surg Am* 78:1004–1014
- Engh CA, Massin P, Suthers KE (1990) Roentgenographic assessment of the biologic fixation of porous-surfaced femoral components. *Clin Orthop Relat Res* 257:107–128
- Massin P, Schmidt L, Engh CA (1989) Evaluation of cementless acetabular component migration. An experimental study. *J Arthroplasty* 4:245–251

24. Delee JG, Charnley J (1976) Radiological demarcation of cemented sockets in total hip replacement. *Clin Orthop Relat Res* 121:20–32
25. Gruen TA, Mcneice GM, Amstutz HC (1979) "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. *Clin Orthop Relat Res* 141:17–27
26. Gallo J, Havranek V, Zapletalova J (2010) Risk factors for accelerated polyethylene wear and osteolysis in ABG I total hip arthroplasty. *Int Orthop* 34:19–26
27. Dorr LD, Wan Z (1995) Ten years of experience with porous acetabular components for revision surgery. *Clin Orthop Relat Res* 319:191–200
28. Rowden NJ, Harrison JA, Graves SE et al (2012) Loss to follow-up after arthroplasty: a new use for registry data. *J Bone Joint Surg Br* 94:493–496
29. Lachiewicz PF, Soileau ES (2012) Second-generation modular acetabular components provide fixation at 10 to 16 years. *Clin Orthop Relat Res* 470:366–372
30. Suckel A, Geiger F, Kinzl L et al (2009) Long-term results for the uncemented Zweymuller/Alloclassic hip endoprosthesis. A 15-year minimum follow-up of 320 hip operations. *J Arthroplasty* 24:846–853
31. Terre RA (2010) Estimated survival probability of the Spotorno total hip arthroplasty after a 15- to 21-year follow-up: one surgeon's results. *Hip Int* 20(Suppl 7):70–78
32. Laupacis A, Bourne R, Rorabeck C et al (2002) Comparison of total hip arthroplasty performed with and without cement: a randomized trial. *J Bone Joint Surg Am* 84:1823–1828
33. Rorabeck CH, Bourne RB, Laupacis A et al (1994) A double-blind study of 250 cases comparing cemented with cementless total hip arthroplasty. Cost-effectiveness and its impact on health-related quality of life. *Clin Orthop Relat Res* 298:156–164
34. Corten K, Bourne RB, Charron KD et al (2011) What works best, a cemented or cementless primary total hip arthroplasty? Minimum 17-year followup of a randomized controlled trial. *Clin Orthop Relat Res* 469:209–217
35. Martín-Guinea J, Álvarez-González P, Nieva-Navarro F (2004) Analysis of 10-year survival rates for 100 cementless Balgrist cups in primary hip prostheses. *J Bone Joint Surg Br* 86:141
36. Rozkydal Z, Janicek P, Tomas T et al (2009) Long-term results of the CLS acetabular cup in primary total hip replacement. *Acta Chir Orthop Traumatol Cech* 76:90–97
37. Döttl C, Steinhauser E, Koch U et al (2006) Fractures of cementless thin-walled cups. *J Arthroplasty* 21:144–147
38. Gallo J, Goodman SB, Konttinen YT et al (2013) Particle disease: Biologic mechanisms of periprosthetic osteolysis in total hip arthroplasty. *Innate Immun* 19:213–224
39. Gallo J, Goodman SB, Lostak J et al (2012) Advantages and disadvantages of ceramic on ceramic total hip arthroplasty: a review. *Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub* 156:204–212
40. Shetty V, Shitole B, Shetty G et al (2011) Optimal bearing surfaces for total hip replacement in the young patient: a meta-analysis. *Int Orthop* 35:1281–1287
41. Battenberg AK, Hopkins JS, Kupiec AD et al (2013) The 2012 Frank Stinchfield Award: Decreasing patient activity with aging: implications for crosslinked polyethylene wear. *Clin Orthop Relat Res* 471:386–392
42. Kinkel S, Wollmerstedt N, Kleinhans JA et al (2009) Patient activity after total hip arthroplasty declines with advancing age. *Clin Orthop Relat Res* 467:2053–2058
43. Schmalzried TP, Shepherd EF, Dorey FJ et al (2000) The John Charnley Award. Wear is a function of use, not time. *Clin Orthop Relat Res* 381:36–46
44. Schmalzried TP, Szuszczewicz ES, Northfield MR et al (1998) Quantitative assessment of walking activity after total hip or knee replacement. *J Bone Joint Surg Am* 80:54–59
45. Romano CL, Frigo C, Randelli G et al (1996) Analysis of the gait of adults who had residua of congenital dysplasia of the hip. *J Bone Joint Surg Am* 78:1468–1479
46. Gould VC, Blom AW, Wyld V (2012) Long-term patient-reported outcomes after total hip replacement: comparison to the general population. *Hip Int* 22:160–165
47. Roder C, Staub LP, Eichler P et al (2006) Avoiding misclassification bias with the traditional Charnley classification: rationale for a fourth Charnley class BB. *J Orthop Res* 24:1803–1808
48. Sheffler LC, Yoo B, Bhandari M et al (2013) Observational studies in orthopaedic surgery: the STROBE statement as a tool for transparent reporting. *J Bone Joint Surg Am* 95:e112–141
49. Joshi AB, Gill GS, Smith PL (2003) Outcome in patients lost to follow-up. *J Arthroplasty* 18:149–153