Clin Orthop Relat Res (2011) 469:1536–1546
DOI 10.1007/s11999-010-1658-0

SYMPOSIUM: UPDATE ON HARD-ON-HARD BEARINGS IN HIP ARTHROPLASTY

Survival of Hard-on-Hard Bearings in Total Hip Arthroplasty

A Systematic Review

Michael G. Zywiel MD, Siraj A. Sayeed MD, Aaron J. Johnson MD, Thomas P. Schmalzried MD, Michael A. Mont MD

Published online: 5 November 2010

Abstract

Background Improvements in prosthetic materials, designs, and implant fixation for THA have led to bearing surface wear being the limitation of this technology. Hard-on-hard bearings promise decreased wear rates and increased survival. However, there may be different survival rates based on bearing materials, manufacturing technologies, and femoral component designs. Additionally, survival rate variability may be based on study design.

Questions/purposes We determined survival rates and study levels of evidence and quality for the following bearings: stemmed metal-on-metal THA, metal-on-metal hip resurfacing, ceramic-on-ceramic THA, and ceramic-on-metal THA.

Methods We performed a systematic review of the peer-reviewed literature addressing THA hard-on-hard bearings. Quality for Level I and II studies was assessed.

Results The four Level I or II second-generation stemmed metal-on-metal THA studies reported between 96% and 100% mean survival at 38 to 60 months. The two Level I hip resurfacing studies reported 94% and 98% mean survival at 56 and 33 months. The four Level I studies of ceramic-on-ceramic THA reported survival from 100% at mean 51 months to 96% at 8 years.

Conclusions While hard-on-hard bearing survival rates have generally been variable with earlier designs, contemporary implants have demonstrated survival of 95% or greater at followup of between 3 and 10 years. Some variability in survival may be due to differences in surgical technique, component positioning, and implant designs. As bearing designs continue to improve with modified materials and manufacturing techniques, use will increase, especially in young and active patients, though concerns remain about the increased reports of adverse events after metal-on-metal bearings.

Introduction

Because of the projected substantial future increase in the need for THA and the increasing demands placed on prostheses by a younger and generally more active patient population than previously treated by surgery, there has been renewed interest in developing new technologies.

Michael A. Mont is a consultant for Stryker Orthopaedics (Mahwah, NJ) and Wright Medical Technology, Inc (Arlington, TN), receives royalties from Stryker, and receives research or institutional support from Stryker, Wright Medical, the National Institutes of Health (NIAMS and NICHD), and TissueGene, Inc (Rockville, MD). Thomas P. Schmalzried is a board member of the Orthopaedic Research and Education Foundation, is a member of the editorial board for *Orthopedics Today*, receives royalties from DePuy Orthopaedics, Inc (Warsaw, IN) and Stryker, is a consultant for Stryker, receives research or institutional support from DePuy and Stryker, and holds stock or stock options in Johnson and Johnson, Smith and Nephew, Stryker, and Zimmer, Inc (Warsaw, IN). Michael G. Zywiel serves on the editorial board of *Expert Review of Medical Devices*. The remaining authors certify that they have no commercial associations (eg, consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.
This work was performed at Sinai Hospital of Baltimore.

M. G. Zywiel, S. A. Sayeed, A. J. Johnson, M. A. Mont (✉)
Center for Joint Preservation and Replacement, The Rubin Institute for Advanced Orthopedics, Sinai Hospital of Baltimore, 2401 West Belvedere Avenue, Baltimore, MD 21215, USA
e-mail: rhondamont@aol.com; mmont@lifebridgehealth.org

T. P. Schmalzried
Joint Replacement Institute at St. Vincent Medical Center, Los Angeles, CA, USA

These will hopefully provide better function, decrease implant wear, and prolong prosthesis survival despite higher activity demands.

Whereas historically THA implant failure was frequently the result of aseptic loosening associated with failure of fixation and implant fracture, improvements in prosthetic materials, designs, and implant fixation resulted in wear of the bearing surface being the primary mechanical limitation of this technology in otherwise correctly implanted metal-on-polyethylene components [47, 84]. Changes in bearing technology have typically focused on increasing implant survival by decreasing articulation wear and resulting osteolysis and reducing dislocation rates. Alternative bearing surfaces are of two types: low-wear metal-on-polyethylene articulations and bearing surfaces using couples other than metal-on-polyethylene. The first encompasses modifications to metal-on-polyethylene articulations to increase their wear resistance. While it has been known for some time gamma irradiation of polyethylene increases wear resistance through crosslinking of the molecular structure [29, 40, 81], historically the clinical application of this altered material was limited because of the concurrent increase in material brittleness with irradiation [8]. More recently, improved strategies for reduction of free radicals during processing, such as serial annealing or doping with antioxidants, allowed for the clinical introduction of second-generation crosslinked polyethylene liners [61, 67, 74]. In vitro studies suggest a 75% to 97% reduction in wear rates compared to conventional polyethylene [21, 62]. Manley and Sutton [56] recently reported metal-on-crosslinked polyethylene bearings are being used in an estimated 70% of primary and revision THAs. This is despite remaining concerns about the material properties of crosslinked polyethylene, such as fatigue strength, fracture toughness, and elongation [66]. The second approach to the development of more wear-resistant bearings has involved the use of hard-on-hard bearing couples. These bearings have the potential to provide advantages in terms of improved implant tribology (lubrication, friction, wear), increased longevity, and reduced dislocation rates. However, there have been concerns about potential disadvantages of these bearings, including potential novel failure modes not typically associated with traditional metal-on-polyethylene articulations and with variable reported survival rates.

In this systematic review, we summarize the published survival rates and study levels of evidence for each of the following hard-on-hard bearing couples: (1) stemmed metal-on-metal THA, (2) metal-on-metal hip resurfacing arthroplasty, (3) ceramic-on-ceramic THA, and (4) ceramic-on-metal THA.

Search Criteria and Strategies

The PubMed database was queried for potentially relevant articles addressing metal-on-metal, ceramic-on-ceramic, and ceramic-on-metal THA or resurfacing hip arthroplasty using the following initial search string: "(((hip[title] and (arthroplasty[title] or replacement[title] or resurfacing [title])) and (metal[title] or ceramic[title] or alumina[title])) OR ((hip[title]) and (resurfacing[title])) OR ((resurfacing[title]) and (arthroplasty[title]) not (patella[title])))." We identified and screened 873 records. Any records meeting the following criteria were excluded: (1) articles not in English; (2) review articles or letters to the editor; (3) reports of the treatment of any joint other than the hip; (4) studies of hard-on-polyethylene articulations (for example, ceramic heads articulating with polyethylene liners); (5) studies of revision of stemmed hip arthroplasties; (6) animal studies; and (7) first-generation total hip resurfacing implants (designs predating contemporary metal-on-metal articulations). We excluded 309 reports based on these criteria (Fig. 1).

The reference lists of the remaining 564 reports were then searched for any additional studies meeting our search and exclusion criteria but not identified at the time of our initial search. An additional 94 records were identified through this process.

To answer our questions, the accumulated manuscripts were screened to identify those meeting the following criteria: (1) reported the survival rates of stemmed or resurfacing metal-on-metal hip arthroplasty, ceramic-on-ceramic THA, or ceramic-on-metal THA in humans; (2) included a minimum of 25 hips; and (3) reported a minimum mean followup of 24 months. Any studies limiting the inclusion of patients based on preoperative diagnosis (with the exception of osteoarthritis) were excluded, and only the report with the longest followup was included in cases of multiple reports of the same patient cohort at different time intervals. The manuscripts meeting these criteria were grouped by the type of bearing interface addressed, and the following data were extracted to a spreadsheet for each: the number of hips and patients studied, followup times, the type of implant and bearing, method of fixation, and survival rates. The study design was assessed using the manuscript guidelines found in the Instructions for Authors of *Clinical Orthopaedics and Related Research,* based on the levels of evidence established by the Centre for Evidence-based Medicine [11].

A total of 64 reports were identified meeting the above criteria: 21 addressed stemmed metal-on-metal THA [9, 13, 16, 19, 20, 23, 30, 35, 39, 51–53, 60, 63, 69, 75, 83, 86, 95, 96, 100], 22 addressed metal-on-metal hip resurfacing arthroplasty [1, 5, 14, 15, 24, 34, 41, 42, 49, 54, 57, 59, 64,

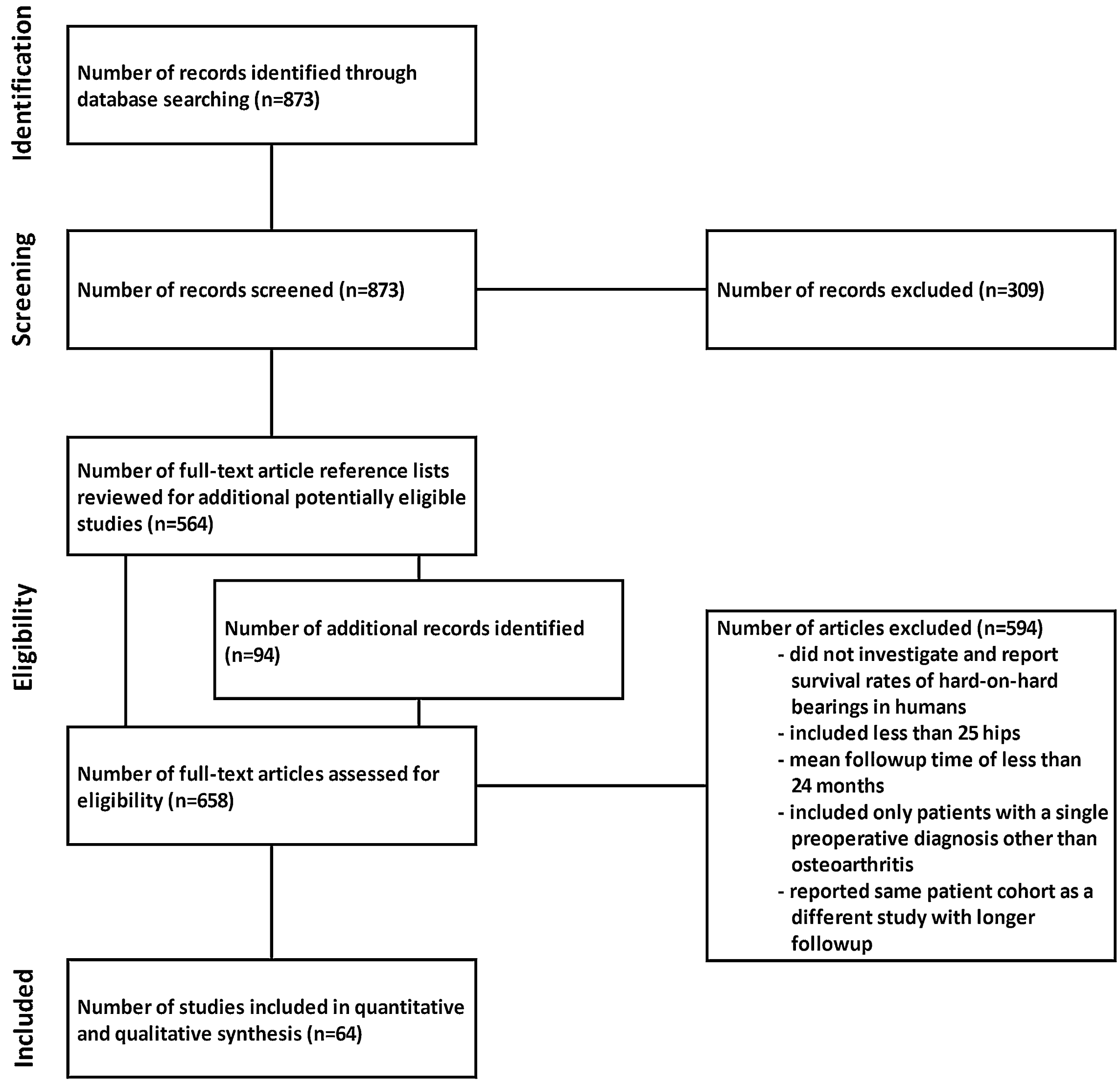

Fig. 1 A flow diagram shows manuscript identification, screening, eligibility, and inclusion

65, 70, 73, 78, 88, 92–94, 101], and 21 reported on ceramic-on-ceramic THA [4, 7, 10, 28, 31–33, 37, 38, 48, 50, 55, 68, 71, 72, 77, 80, 85, 90, 98, 99]. The number of studies with each level of evidence from I to IV is summarized (Table 1). No reports meeting the above criteria were identified that addressed ceramic-on-metal THA.

The quality of studies with a level of evidence of I and II was assessed for internal validity by three of the authors (MGZ, AJJ, SAS), with any discrepancies resolved by discussion and consensus. First, studies were reviewed to confirm a randomized, controlled design. Two studies did not meet this criterion and were excluded from further analysis. The following parameters were graded as done, not done, or unclear for the remaining 10 studies based on the Cochrane guidelines [82]: randomization, allocation concealment, and blinding (of participants, assessors, and analysts). Additionally, the following study factors were rated as adequate, inadequate, or unclear: baseline comparability of groups based on demographic factors (statistically similar age, body mass index, gender, and preoperative diagnosis to qualify as adequate) and

Table 1. Number of studies for each bearing couple stratified by level of evidence

Type of bearing	Level of evidence			
	I	II	III	IV
Stemmed metal-on-metal	3	1	1	16
Metal-on-metal resurfacing	2	1	4	15
Ceramic-on-ceramic	4	1	1	15
Ceramic-on-metal	0	0	0	0

Table 2. Summarized results of study quality analysis

Study	Level of evidence	Randomization	Allocation concealment	Blinding			Baseline comparability	Followup
				Participants	Assessors	Analysts		
Second-generation stemmed metal-on-metal THA								
Zijlstra et al. [100] (2009)	I	Done	Done	Unclear	Not done	Unclear	Adequate	Adequate
Jacobs et al. [39] (2004)	I	Unclear	Unclear	Unclear	Unclear	Unclear	Adequate	Inadequate
MacDonald et al. [53] (2003)	I	Done	Done	Unclear	Unclear	Unclear	Unclear	Adequate
Lombardi et al. [51] (2001)	II	Done	Unclear	Unclear	Unclear	Unclear	Adequate	Adequate
Metal-on-metal resurfacing								
Vendittoli et al. [94] (2010)	I	Done	Done	Not Done	Not done	Unclear	Yes	Unclear*
Ceramic-on-ceramic (second-generation alumina)								
Lewis et al. [48] (2010)	I	Done	Done	Done	Unclear	Unclear	Unclear	Adequate
Bascarevic et al. [4] (2009)	I	Done	Unclear	Unclear	Unclear	Unclear	Adequate	Unclear*
Capello et al. [10] (2008)	I	Unclear	Unclear	Unclear	Unclear	Unclear	Adequate	Unclear*
Ceramic-on-ceramic (alumina composite)								
Hamilton et al. [32] (2010)	I	Done	Done	Unclear	Unclear	Unclear	Adequate	Adequate
Lombardi et al. [50] (2010)†	II	Done	Done	Unclear	Unclear	Unclear	Unclear	Adequate

* It appears none of the patients were lost to followup, but this is not explicitly stated in the report; †study of composite femoral head on pure alumina liner

followup (no more than 10% of individuals from any one study arm lost to followup to qualify as adequate). All of the studies had deficiencies in at least one of the above quality dimensions, with a failure to properly blind participants, assessors, and analysts or to explicitly report the blinded parties occurring most commonly (Table 2).

Results

The 21 studies addressing stemmed metal-on-metal THA reported survival rates of 71% to 100% at mean followups ranging from 36 to 336 months (Table 3). Four studies encompassed first-generation metal-on-metal bearings [9, 13, 35, 60] that predated the introduction of high-tolerance bearings and improved metal alloys. These studies reported survival rates ranging from as high as 96% at a mean followup of 36 months (range, 24–48 months) to as low as 71% at a mean followup of 135 months (range, 24–140 months). All four studies were Level IV. Seventeen studies encompassed second-generation metal-on-metal bearings [16, 19, 20, 23, 30, 39, 51–53, 63, 69, 75, 83, 86, 95, 96, 100]. These studies reported survival ranging from 93% at 120 months to 100% at a mean followup of 60 months (range, 44–88 months). The longest reported mean followup was 126 months (range, 120–143 months), with a survival rate of 94%. The four Level I or II studies reported survival rates of between 96% and 100% at mean followups ranging from 38 to 60 months [39, 51, 53, 100].

The 22 studies addressing metal-on-metal hip resurfacing arthroplasty reported survival rates of 84% to 100% at mean followups ranging from 39 to 89 months (Table 4). Three reports were Level I or II studies [59, 65, 94], whereas 16 were Level IV. The two Level I studies reported survival rates of 94% at a mean followup of 56 months (range, 36–72 months) and 98% at a mean followup of 33 months (range, 24–60 months) [56, 78]. The single Level II study reported a survival rate of 95% at a mean followup of 36 months (range, 24–72 months) [59].

The 21 studies addressing ceramic-on-ceramic THA reported survival rates of 73% to 100% at mean followups ranging from 31 to 240 months (Table 5). The studies were grouped based on advances in ceramic composition and manufacturing that are beyond the scope of the present report but have been described elsewhere [58, 97]. Eight studies encompassed first-generation alumina bearings [37, 55, 71, 72, 77, 80, 85, 98] predominantly used until the mid 1990 s, before the introduction of improved raw materials and manufacturing technologies. These studies reported survival rates ranging from 96% at an unreported mean followup (range, 2–11 years) to a 73% survival at a mean followup of 37 months (range, 24–52 months). All of these studies were Level IV. Eleven studies reported on second-generation alumina bearings [4, 7, 10, 28, 31, 33, 38, 48, 68, 90, 99], produced with smaller base material grain size, increased material purity, and high-pressure ceramic fusion techniques. Three of these studies were Level I [4, 10, 48] and reported survival rates ranging from 100% at a mean followup of 51 months (range, 34–63 months) to 96% at 8 years. The remaining nine studies were Level III or IV. Two of the studies reported one specific polyethylene-ceramic

Table 3. Reported survival rates of first- and second-generation stemmed metal-on-metal THA

Study	Number of hips (patients)	Type of bearing design	Followup (months)*	Femoral fixation	Acetabular fixation	Survival (%)	Level of evidence
First generation							
Brown et al. [9] (2002)	123 (101)	Modified low-tolerance CoCrMo	336	Cemented	Cemented	74†	IV
Higuchi et al. [35] (1997)	38 (38)	Modified low-tolerance CoCrMo	135 (24–240)	Cemented	Cemented	71	IV
Dandy and Theodorou [13] (1975)	739 (NR)	Modified low-tolerance CoCrMo	60 (24–96)	Cemented	Cemented	93	IV
McKee and Watson-Farrar [60] (1966)	50 (50)	Low-tolerance CoCrMo	36 (24–48)	Cemented	Cemented	96	IV
Second generation							
Neumann et al. [69] (2010)	100 (99)	High-tolerance CoCrMo	126 (120–143)	Uncemented	Uncemented	94	IV
Paleochorlidis et al. [75] (2009)	99 (84)	High-tolerance CoCrMo	114 (72–180)	Uncemented	Uncemented	95	IV
Zijlstra et al. [100] (2009)	102 (NR)	High-tolerance CoCrMo	60	Cemented	Cemented	97†	I
Dastane et al. [16] (2008)	82 (80)	High-tolerance CoCrMo	66 (26–140)	Uncemented	Uncemented	99	III
Delaunay et al. [19] (2008)	83 (73)	High-tolerance CoCrMo	120	Uncemented	Uncemented	96†	IV
Eswaramoorthy et al. [23] (2008)	85 (82)	High-tolerance CoCrMo	120	Uncemented	Cemented	96†	IV
Grubl et al. [30] (2007)	105 (98)	High-tolerance CoCrMo	120	Uncemented	Uncemented	99†	IV
Sharma et al. [86] (2007)	209	High-tolerance CoCrMo	72 (60–132)	Cemented	Cemented	95	IV
Milosev et al. [63] (2006)	640 (591)	High-tolerance CoCrMo	120	Uncemented	Uncemented	93†	IV
Saito et al. [83] (2006)	106 (90)	High-tolerance CoCrMo	72 (60–96)	Uncemented	Cemented	99	IV
Jacobs et al. [39] (2004)	95 (95)	High-tolerance CoCrMo	40 (36–68)	Uncemented	Uncemented	99	I
Long et al. [52] (2004)	161 (154)	High-tolerance CoCrMo	76 (24–108)	Uncemented	Uncemented	96	IV
MacDonald et al. [53] (2003)	22 (22)	High-tolerance CoCrMo	38 (26–47)	Uncemented	Uncemented	100	I
Lombardi et al. [51] (2001)	78 (78)	High-tolerance CoCrMo	39 (23–62)	Uncemented	Uncemented	100	II
Dorr et al. [20] (2000)	70 (70)	High-tolerance CoCrMo	60 (48–84)	Uncemented	Uncemented	98	IV
Wagner and Wagner [95] (2000)	76 (76)	High-tolerance CoCrMo	60 (44–88)	Uncemented	Uncemented	100	IV
Weber [96] (1996)	100 (98)	High-tolerance CoCrMo	48 (24–84)	Uncemented	Uncemented	95	IV

* Values are expressed as mean, with range in parentheses; †survivorship at noted followup time; NR = not reported; CoCrMo = cobalt-chromium-molybdenum.

sandwich construction liner [33, 38] and found lower survival rates of 83% and 91%, respectively. The survival rates in the remaining reports ranged from 94% to 100%. Two studies reported the results of new-generation alumina matrix composite components (for example, combining alumina with specific smaller proportions of zirconia, chromium oxide, and strontium). The Level I study reported 98% survival at a mean followup of 31 months (range, 21–49 months) [32], while the Level II study reported 95% survival at a mean followup of 73 months (range, 26–108 months) [50].

We identified no studies reporting survival of ceramic-on-metal THA.

Discussion

Despite the popularity of metal-on-polyethylene articulation usage since THA was first popularized a half-century ago, hard-on-hard bearings have consistently been used, though to a lesser extent. However, their use has been more controversial, with some surgeons advocating the use of hard-on-hard couples in virtually all patients, and others arguing the potential for adverse events preclude their use in virtually all arthroplasty procedures. Achieving a consensus concerning their use has been further complicated by the dominance of case series and case study reports that have a high potential for study bias and for over- or

Table 4. Reported survival rates of contemporary metal-on-metal hip resurfacing arthroplasty

Study	Number of hips (patients)	Type of bearing design	Followup (months)*	Femoral fixation	Acetabular fixation	Survival (%)	Level of evidence
Daniel et al. [15] (2010)	184 (160)	CoCrMo resurfacing	84 (24–130)	Cemented	Uncemented	84	IV
Madhu et al. [54] (2010)	117 (101)	CoCrMo resurfacing	84 (60–113)	Cemented	Uncemented	93	IV
Vendittoli et al. [94] (2010)	109 (NR)	CoCrMo resurfacing	56 (36–72)	Cemented	Uncemented	94	I
Bergeron et al. [5] (2009)	228 (209)	CoCrMo resurfacing	55	Cemented	Uncemented	97†	IV
Killampalli et al. [41] (2009)	100 (100)	CoCrMo resurfacing	NR (24–60)	Cemented	Uncemented	100	IV
Mont et al. [64] (2009)	54 (54)	CoCrMo resurfacing	40 (24–60)	Cemented	Uncemented	96	III
Ollivere et al. [73] (2009)	104 (94)	CoCrMo resurfacing	61 (38–76)	Cemented	Uncemented	100	IV
Zywiel et al. [101] (2009)	33 (33)	CoCrMo resurfacing	45 (24–67)	Cemented	Uncemented	100	III
Amstutz and LeDuff [1] (2008)	1000 (838)	CoCrMo resurfacing	68 (13–133)	Cemented	Uncemented	95	IV
Falez et al. [24] (2008)	60 (58)	CoCrMo resurfacing	32 (2–44)	Cemented	Uncemented	92	IV
Heilpern et al. [34] (2008)	110 (98)	CoCrMo resurfacing	71 (60–93)	Cemented	Uncemented	96	IV
Kim et al. [42] (2008)	200 (200)	CoCrMo resurfacing	31 (12–54)	Cemented	Uncemented	93	IV
McGrath et al. [59] (2008)	40 (35)	CoCrMo resurfacing	36 (24–72)	Cemented	Uncemented	95	II
Steffen et al. [88] (2008)	610 (532)	CoCrMo resurfacing	60 (24–96)	Cemented	Uncemented	95	IV
Marker et al. [57] (2007)	550 (NR)	CoCrMo resurfacing	44 (7–75)	Cemented	Uncemented	93	IV
Mont et al. [65] (2007)	1016 (906)	CoCrMo resurfacing	33 (24–66)	Cemented	Uncemented	94	I
Nishii et al. [70] (2007)	50 (45)	CoCrMo resurfacing	60	Cemented	Uncemented	96†	IV
Pollard et al. [78] (2006)	63 (NR)	CoCrMo resurfacing	61 (52–71)	Cemented	Uncemented	94	III
Vail et al. [93] (2006)	57 (52)	CoCrMo resurfacing	36 (24–48)	Cemented	Uncemented	97	III
Lilikakis et al. [49] (2005)	70 (66)	CoCrMo resurfacing	29 (24–38)	Uncemented	Uncemented	97	IV
Treacy et al. [92] (2005)	144 (130)	CoCrMo resurfacing	60	Cemented	Uncemented	98†	IV
Daniel et al. [14] (2004)	446 (384)	CoCrMo resurfacing	39 (24–98)	Cemented	Uncemented	99	IV

* Values are expressed as mean, with range in parentheses; †survivorship at noted followup time; NR = not reported; CoCrMo = cobalt-chromium-molybdenum.

underestimating the true survival rates of these bearings. These factors motivated us to undertake this review to systematically assess the published evidence concerning the survival of several commonly used alternative bearing surfaces for THA.

We acknowledge the following limitations of our study. First, while we have limited our inclusion criteria to reports written in English, some of the bearing couples were developed and used extensively in non-English-speaking countries and their results were reported in several respected native-language journals. For example, much of the research and development of ceramic prostheses occurred, and continues to take place, in France and Germany, and it is likely there are many reports published in French or German that would meet all of our inclusion criteria, with the exception of the language restriction. With English currently being the de facto universal academic language in the Western world and with more than 20 studies included for each of the investigated bearing couples, we believe these studies will provide an overview of the currently known survival rates of these articulating couples. Second, the majority of the studies identified had a nonrandomized design, and the remaining reports had one or more deficiencies in quality compromising internal validity, increasing the potential for selection, performance, attrition, and assessment bias. Furthermore, substantial variability in the study methods and data reporting resulted in considerable heterogeneity and precluded the possibility of accurate aggregation or comparison of the reported findings across multiple studies. Third, there are other factors that may contribute to implant survival that were not included in our analysis and were often not reported in studies, such as differences in femoral and acetabular component design and fixation, femoral head diameter, and implant positioning. Fourth, many of the included reports originate from well-known centers with procedures performed by high-volume subspecialty-trained surgeon-innovators, and the results may not necessarily accurately reflect those that would be achieved by general orthopaedists or those who perform a smaller number of cases on an annual basis. Fifth, because of the relatively recent introduction of modern resurfacing components, the series with longer followups typically involve patients operated on during a period where appropriate patient indications were being explored and components and instrumentation were being developed. However, for

Table 5. Selected reported survival rates of historical and modern ceramic-on-ceramic bearings

Study	Number of hips (patients)	Followup (months)*	Survival (%)	Level of evidence
Early-generation alumina				
Petsatodis et al. [77] (2010)	85 (78)	240	84‡	IV
Huo et al. [37] (1996)	27 (25)	73 (60–95)	85	IV
Riska [80] (1993)	290 (255)	64 (24–144)	92	IV
Nizard et al. [71] (1992)	187 (172)	120	83‡	IV
Winter et al. [98] (1992)	100 (100)	NR (120–168)	75	IV
Mahoney and Dimon [55] (1990)	42 (34)	51 (27–66)	83	IV
Sedel et al. [85] (1990)	54 (NR)	NR (24–132)	96	IV
O'Leary et al. [72] (1988)	69 (62)	37 (24–52)	73	IV
Late-generation alumina				
Lewis et al. [48] (2010)	30 (30)	100 (58–121)	97	I
Bascarevic et al. [4] (2009)	82 (78)	51 (34–63)	100	I
Greene et al. [28] (2009)	103 (97)	50 (48–64)	100	IV
Capello et al. [10] (2008)	380 (275)	96 (60–NR)	96‡	I
Iwakiri et al. [38] (2008)	82 (77)	80 (60–100)	91	IV
Ha et al. [31] (2007)	74 (64)	66 (60–72)	100	IV
Sugano et al. [90] (2007)	170 (143)	72 (60–96)	99	III
Hasegawa et al. [33] (2006)	35 (30)	70 (60–77)	83	IV
Murphy et al. [68] (2006)	194 (173)	50 (24–108)	96	IV
Yoo et al. [99] (2005)	93 (79)	68 (60–73)	100	IV
Bizot et al. [7] (2004)	71 (62)	108	94‡	IV
Alumina composite				
Hamilton et al. [32] (2010)	177 (NR)	31 (21–49)	98	I
Lombardi et al. [50] (2010)†	65 (NR)	73 (26–108)	95	II

* Values are expressed as mean, with range in parentheses; †study of composite femoral head on pure alumina liner; ‡survivorship at noted followup time; NR = not reported.

all bearing types, the majority of studies, especially those with longer followups, have low levels of evidence (III and IV), raising questions about the potential for positive outcome bias [22, 36, 89] that may not accurately reflect the survival most surgeons can expect to achieve. Additionally, most of the Level I studies have mean followups of 5 years or less, further limiting the ability to discern purported differences in long-term survival in hip arthroplasty among different types of hard-on-hard bearings. This paucity of prospective, comparative studies limits the ability to evaluate the potential advantages in terms of survival of hard-on-hard bearings compared to metal-on-polyethylene articulations. Finally, even when such studies are conducted, they are complicated by the large number of subjects needed for an adequately powered comparison of survival rates. For example, assuming a power of 0.8 and alpha of 0.05, approximately 870 hips would need to be enrolled for a 5% difference in survival rates (95% versus 90%) to reach significance. Even with a 10% difference in survival (95% versus 85%), 280 subjects would be required. Nevertheless, despite these and other potential limitations, we believe our study presents important findings in terms of the short- to mid-term survival rates of contemporary hard-on-hard bearings in hip arthroplasty.

Our findings suggest modern metal-on-metal THA consistently provides survivorship of 95% or more at followups from 3 to 10 years, and it is hoped the large majority of these prostheses will continue to demonstrate similar survival at longer followups. The availability of near-anatomic femoral head sizes and the extremely low in vitro wear rates of these bearings, even when compared to modern crosslinked polyethylene liners, theoretically make them an appropriate choice in young and highly active patients. However, additional clinical evidence and longer followup are needed to confirm these claims.

Modern metal-on-metal hip resurfacing similarly appears to provide survival rates of 95% and more at followup times currently approaching 10 years when performed by experienced surgeons in properly selected patients. This procedure may be especially suitable for young, active patients because it may provide unique benefits in terms of preservation of femoral bone stock, increased postoperative activity levels, and potentially more natural joint biomechanics. However, additional evidence in direct comparison to other hip arthroplasty prostheses is necessary to confirm these suggestions. Additionally, hip resurfacing is a distinct procedure requiring surgeons to learn techniques different from those used for standard THA. It is a technically demanding procedure associated with a substantial learning curve. Intraoperative notching of the femoral neck must be avoided to minimize the risk of postoperative femoral neck fractures [17, 57, 87]. Additionally, adequate acetabular cup coverage and appropriate femoral component positioning, as well as removal of all osteophytes, are necessary to minimize the likelihood of impingement and/or groin pain [6, 46]. Finally, proper case selection is critical as patients with poor bone quality (due to osteopenia or extensive osteonecrosis of the femoral head), large femoral head or neck cysts, or smaller femoral neck sizes are susceptible to catastrophic femoral neck fractures [65].

While early ceramic-on-ceramic implants were characterized by high failure rates as a result of both component fracture and loosening of the monolithic acetabular components, advances in component design and manufacturing technology have resulted in modern implants having substantially higher survival rates, very low wear, and an extremely low incidence of femoral head fracture (0.19% combined in the studies included in the present analysis, and an estimated 0.012% in the largest reported series to date of approximately 500,000 femoral heads [97]). Nonetheless, concerns remain about the possibility of component chipping and noisy implants. Ongoing research and advances in ceramic technology and implant design may succeed in addressing these disadvantages in the future [3, 12, 79]. Recently, some authors have recommended the use of a ceramic-on-highly-crosslinked polyethylene bearing in younger active patients, which is postulated to provide low wear rates while minimizing the possibility of component chipping or squeaking. In a prospective randomized study of 177 modern ceramic-on-ceramic and 87 ceramic-on-highly-crosslinked polyethylene THAs, Hamilton et al. [32] reported similar survivorship and complication rates in both groups at a mean followup of 31 months (range, 21–49 months), with no squeaking reported in either group. Data from other investigators and over longer followup periods are needed to ascertain whether this is an appropriate alternative.

The use of ceramic-on-metal bearing couples has been proposed as an alternative that may provide benefits in terms of wear similar to those of ceramic-on-ceramic articulations, while further decreasing the incidence of component chipping or squeaking. However, while investigative studies are underway to assess these potential benefits, no currently published evidence was identified to support these claims.

Although not specifically assessed in our review, there has been a recent increase in concern among the orthopaedic community about the potential for both local and systemic distribution of metal debris and especially with the potential for adverse local tissue reactions. A number of reports from the Nuffield Orthopaedic Centre in Oxford, United Kingdom, have provided some insight into these complications. Pandit et al. [76] reported symptomatic pseudotumors in 20 hips treated with metal-on-metal hip resurfacing in 17 patients and estimated the incidence of this complication at 1%. Kwon et al. [44] suggested the incidence of asymptomatic pseudotumors after hip resurfacing may be as high as 6.5%, with almost all identified cases occurring in patients with implant sizes of 50 mm or less. Glyn-Jones et al. [25] suggested the incidence of symptomatic pseudotumors may increase with time. A subsequent report from Kwon et al. [43] identified a higher wear rate in resurfacing patients revised for symptomatic tissue reactions as compared to those revised for other reasons with evident edge loading of retrieved components in all cases. Interestingly, these reactions are not limited to metal-on-metal articulations. Svensson et al. [91] reported a case of pseudotumor formation 2.5 years after uncemented metal-on-polyethylene THA associated with corrosion at the prosthesis head-neck junction. While adverse local tissue reactions do appear to be associated with abnormally high metal particle generation rates secondary to factors such as poor implant positioning and/or suboptimal prosthesis design [2, 18, 44, 45], the causes are likely multifactorial and the true incidence remains unknown. However, it is clear these adverse local tissue reactions, if not identified and revised promptly, can result in substantial periarticular soft tissue destruction and poor outcomes of revision surgery [26]. Although national joint registry data suggest overall revision rates of modern standard head size metal-on-metal articulations appear to be similar to, or lower than, those found with metal-on-ceramic and ceramic-on-ceramic articulations [27], in the absence of additional evidence to more accurately assess the incidence and predisposing factors of adverse reactions, patients should be made aware of the risks associated with these bearings. Their use should be approached with caution in women of childbearing age and avoided in patients with a history of metal sensitivity. Nevertheless, even a relatively low incidence of these complications may be unacceptable to both surgeons and patients, and the use of metal-on-metal articulations may decrease unless they can be reliably avoided. As a result, it is critical a full understanding of the factors leading to these reactions be achieved to further reduce their incidence.

In general, while hip arthroplasties using earlier-generation hard-on-hard bearings had more variable survival rates, contemporary designs are consistently reported to have good survival rates. The majority of authors reported 95% or more of stemmed THA implants remain in situ, regardless of the specific bearing couple used at mean followups of between 3 and 10 years. It is worth noting, though, some of the clinical successes may have been the result of improvements in implant fixation techniques and design parameters. The survival rates for hip resurfacing are somewhat more variable.

High short- and mid-term survival rates have been reported by a number of investigators with each of the studied hard-on-hard bearings. Adverse events from many of these hard-on-hard bearings can be minimized by appropriate patient selection and surgical technique. As bearing designs continue to improve with new and modified materials, improved manufacturing techniques, and a better understanding of factors associated with potential adverse reactions, the use of hard-on-hard bearings may increase, especially in young and active patients. However, an increased emphasis in the orthopaedic community on well-designed prospective comparative studies, high-quality systematic reviews, and the development of a comprehensive joint registry are critical to accurately assess many of the potential advantages and disadvantages ascribed to these developing technologies, as well as the influence of various patient and implant factors on outcomes and survival rates.

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