Which Implant Should We Use for Primary Total Hip Replacement?

Keurentjes, J.C.; Pijls, B.G.; Tol, F.R. van; Mentink, J.F.; Mes, S.D.; Schoones, J.W.; ... ; Nelissen, R.G.

Which Implant Should We Use for Primary Total Hip Replacement?

A Systematic Review and Meta-Analysis

J. Christiaan Keurentjes, MD, Bart G. Pijls, MD, PhD, Floris R. Van Tol, MSc, Jill F. Mentink, MD, Stephanie D. Mes, MD, Jan W. Schoones, MSc, Marta Fiocco, PhD, Art Sedrakyan, MD, PhD, and Rob G. Nelissen, MD, PhD

Investigation performed at the Department of Orthopaedic Surgery, Leiden University Medical Center, Leiden, the Netherlands

Background: Many total hip implants are currently available on the market worldwide. We aimed to estimate the probability of revision surgery at ten years for each individual total hip implant and to compare these estimates with the National Institute for Health and Care Excellence (NICE) benchmark.

Methods: We performed a meta-analysis of cohort studies. The methodological quality was assessed with use of the Assessment of Quality in Lower Limb Arthroplasty (AQUILA) checklist. We searched PubMed, Embase, Web of Science, and the Cochrane Library. Additionally, national joint registries that were full members of the International Society of Arthroplasty Registers (ISAR) were hand searched. Studies in which the authors reported the survival probability for either the acetabular or the femoral component of primary total hip replacements with use of revision for any reason or for aseptic loosening at ten years as the end point, with at least 100 implants at baseline, and in which at least 60% of the patients had primary osteoarthritis were eligible for inclusion.

Results: The search strategy revealed 5513 papers describing survival probabilities for thirty-four types of acetabular components and thirty-two types of femoral components. Eight types of acetabular cups and fifteen types of femoral stems performed better than the NICE benchmark.

Conclusions: We recommend that surgeons performing a primary total hip replacement use an implant that outperforms the NICE benchmarks.

Total hip replacement is an effective surgical intervention to alleviate pain, restore functionality of the hip, and improve the quality of life of patients with end-stage degeneration of the hip joint[1-4]. Currently, a wide variety of total hip implants is available to orthopaedic surgeons worldwide[5]. Many factors, such as the cost of the implant, familiarity with the design and instruments, and ease of use, influence the surgeon's choice of a particular total hip implant. Arguably, from both a patient and a societal perspective, the most important factor is the clinical performance of the total hip implant and the probability of revision surgery during a given period of time. Revision hip arthroplasty is technically challenging with a higher complication rate, a longer hospital stay, and a higher cost than primary total hip replacement and can lead to disability and death[6-10]. Clearly, choosing a total hip implant that is associated with the lowest rate of revision surgery can prevent harm and reduce long-term health-care costs. Recently, the National Institute for Health and Care Excellence (NICE) suggested a ten-year revision rate of ≤10% as an acceptable benchmark performance of a primary total hip implant, which was loosely based on an earlier report by Murray et al.[5,11].

The objective of our study was to systematically search and appraise the literature to estimate the probability of revision surgery at ten years for each individual type of total hip implant. Additionally, we sought to compare the estimates of

Disclosure: None of the authors received payments or services, either directly or indirectly (i.e., via his or her institution), from a third party in support of any aspect of this work. None of the authors, or their institution(s), have had any financial relationship, in the thirty-six months prior to submission of this work, with any entity in the biomedical arena that could be perceived to influence or have the potential to influence what is written in this work. Also, no author has had any other relationships, or has engaged in any other activities, that could be perceived to influence or have the potential to influence what is written in this work. The complete **Disclosures of Potential Conflicts of Interest** submitted by authors are always provided with the online version of the article.

TABLE I Characteristics of Studies Describing Survival Probabilities of Acetabular Cups with Revision for Any Reason as the End Point

Cup	Ref.	Manufacturer	Country of Study Origin	No. at Baseline
ABG I	23	Howmedica, East Rutherford, NJ	Finland	108
ABG I	22	Howmedica	Wales	100
ABG II HA	21	Not specified	Sweden	213
ACS Triloc+	24	DePuy, Warsaw, IN	U.S.	394
Arthopor	24	Joint Medical Products, Stamford, CT	U.S.	433
ATLAS II	25	Not specified	France	171
ATLAS III	25	Not specified	France	126
Charnley	26	Thackray, Leeds, U.K.	U.S.	238
Charnley	21	Not specified	Sweden	23,272
Charnley Elite	21	Not specified	Sweden	9456
CLS Spotorno	21	Not specified	Sweden	1169
Conserve Plus	27	Wright Medical Technology, Arlington, TN	U.S.	100
Exeter All-Polyethylene	28	Stryker	U.K.	263
Exeter Duration	21	Not specified	Sweden	11,712
Fitmore	29	Sulzer/Zimmer Orthopaedics	U.K.	119
Harris Design-2	30	Howmedica, Rutherford, NJ	Sweden	126
Harris-Galante I	31	Zimmer	Denmark	324
Harris-Galante II	23	Zimmer	Finland	277
Hofer-Imhof	32	Not specified	Austria	678
JRI Threaded Cup	33	Joint Replacement Instrumentation, London, U.K.	U.K.	112
Lubinus	21	Not specified	Sweden	76,047
Lubinus Eccentric	34	Waldemar-Link	Finland	444
Mallory-Head Cementless	23	Biomet, Warsaw, IN	Finland	110
Mallory-Head Cementless	35	Biomet	Canada	307
Miami Orthopaedic Surgical Clinic: All Polyethylene	26	Biomet	U.S.	100
Miami Orthopaedic Surgical Clinic: Metal Backed	26	Biomet	U.S.	134
Morscher Press Fit	37	Zimmer	Switzerland	124
Morscher Press Fit	36	Sulzer Orthopedics/Zimmer, Winterthur, Switzerland	New Zealand	125
Mueller	26	DePuy International, Leeds, U.K.	U.S.	141
Novae	38	SERF, 85 Chemin des Bruyères, F-69150 Decines	France	135
PCA Pegged	23	Howmedica, East Rutherford, NJ	Finland	122
Plasmacup	39	B Braun, Sheffield, U.K.	U.K.	318
RM	40	Mathys, Bettlach, Switzerland	Netherlands	630
Romanus	23	Biomet	Finland	114
T-28	26	Zimmer	U.S.	559
T-28	41	Zimmer	U.S.	132
Trilogy HA	21	Not specified	Sweden	1196
Universal	23	Biomet	Finland	898
Universal	42	Biomet	U.S.	114
Zweymüller-Alloclassic Screw Cup	44	Sulzer Orthopedics/Zimmer, Winterthur, Switzerland	Germany	320
Zweymüller-Alloclassic Screw Cup	43	Sulzer Orthopedics/Zimmer, Winterthur, Switzerland	Germany	139

TABLE II Characteristics of Studies Describing Survival Probabilities of Femoral Stems with Revision for Any Reason as the End Point

Stem	Ref.	Manufacturer	Country of Study Origin	No. at Baseline
ABG I	23	Stryker	Finland	390
ABG I	22	Howmedica, East Rutherford, NJ	U.K.	100
ABG I	21	Not specified	Sweden	370
Anatomic Mesh	23	Zimmer, Warsaw, IN	Finland	135
Bicontact	45	B.Braun-Aesculap, Tuttlingen, Germany	Germany	250
Bi-Metric	46	Biomet	Sweden	115
Bi-Metric	23	Biomet	Finland	1982
Bi-Metric	47	Biomet	U.S.	129
Charnley	48	Johnson & Johnson	U.S.	160
Charnley	21	Not specified	Sweden	23,272
CLS Spotorno	23	Sulzer-medica, Winterthur, Switzerland	Finland	108
CLS Spotorno	21	Not specified	Sweden	1169
Conserve Plus	27	Wright Medical Technology, Arlington, TN	U.S.	100
Corail	49	DePuy, France	France	120
Exeter Polished	21	Not specified	Sweden	11,712
Exeter Universal	50	Howmedica, East Rutherford, NJ	U.K.	230
Freeman Cementless	51	Finsbury Instruments, Leatherhead, U.K.	U.K.	100
Furlong	33	Joint Replacement Instrumentation, London, U.K.	U.K.	134
Harvard Femoral Stem	52	Harvard Health Care, Wakefield, West Yorkshire, U.K.	U.K.	269
Heritage	53	Zimmer, Warsaw, IN	U.S.	283
Iowa polished	53	Zimmer, Warsaw, IN	U.S.	120
Lord Madreporique	23	Benoist Girard, Bagneux, France	Finland	286
Lord Madreporique	54	Benoist Girard, Bagneux, France	Norway	116
Lubinus IP	55	Waldemar Link, Hamburg, Germany	Finland	280
Lubinus IP	34	Waldemar Link, Hamburg, Germany	Finland	257
Lubinus SP	55	Waldemar Link, Hamburg, Germany	Finland	263
Lubinus SP	34	Waldemar Link, Hamburg, Germany	Finland	185
Lubinus SP II	21	Not specified	Sweden	76,047
Mallory-Head Cemented	56	Biomet	U.S.	102
Mallory-Head Cementless	57	Biomet, Warsaw, IN	U.S.	2000
Mallory-Head Cementless	35	Biomet	Canada	307
MS-30	37	Zimmer, Warsaw, IN	Switzerland	124
Omnifit Cemented	48	Osteonics, Allendale, NJ	U.S.	305
Osteonics Cementless	58	Stryker	U.S.	226
PCA	23	Howmedica, East Rutherford, NJ	Finland	111
Profile Porous	23	DePuy International, Leeds, U.K.	Finland	115
R-B Interlok	48	Biomet	U.S.	235
SBG	59	Plus Orthopaedics, Rotkreuz, Switzerland	Austria	230
Stanmore Custom Made	60	DePuy International, Leeds, U.K.	Italy	129
Taperloc	61	Biomet	U.S.	129
Triumph	53	Zimmer, Warsaw, IN	U.S.	148
Zweymüller SL	44	Zimmer, Winterthur, Switzerland	Germany	320

TABLE III Characteristics of Studies Describing Survival Probabilities of Acetabular Cups with Revision for Aseptic Loosening as the End Point

Cup	Ref.	Manufacturer	Country of Study Origin	No. at Baseline
ABG I	23	Howmedica, East Rutherford, NJ	Finland	108
ACS Triloc+	24	DePuy, Warsaw, IN	U.S.	394
Arthopor	24	Joint Medical Products, Stamford, CT	U.S.	433
Brunswik	62	Not specified	Sweden	151
Charnley	63	DePuy, Leeds, U.K.	Norway	9186
Charnley	62	Not specified	Sweden	204
Charnley	64	Not specified	Norway	14,842
Charnley	26	Thackrey, Leeds, U.K.	U.S.	238
Charnley All-Polyethylene	65	Zimmer	U.S.	193
Conserve Plus	27	Wright Medical Technology, Arlington, TN	U.S.	100
Elite Ogee	50	DePuy International, Leeds, U.K.	U.K.	218
Exeter	64	Not specified	Norway	3934
Exeter All-Polyethylene	28	Stryker	U.K.	263
Fitmore	29	Sulzer/Zimmer Orthopaedics	U.K.	119
Harris Design-2 All-Polyethylene	66	Howmedica, East Rutherford, NJ	Canada	195
Harris-Galante II	23	Zimmer	Finland	277
Hofer-Imhof	67	Smith and Nephew, Rotkreuz, Switzerland	Austria	100
Hofer-Imhof	32	Not specified	Austria	678
JRI Threaded Cup	33	Joint Replacement Instrumentation, London, U.K.	U.K.	134
Link	64	Not specified	Norway	413
Lord Threaded	54	Benoist Girard	Norway	116
Mallory-Head Cementless	23	Biomet, Warsaw, IN	Finland	110
Miami Orthopaedic Surgical Clinic: All Polyethylene	26	Biomet	U.S.	100
Miami Orthopaedic Surgical Clinic: Metal Backed	26	Biomet	U.S.	134
Morscher Press Fit	37	Zimmer	Switzerland	124
Morscher Press Fit	36	Sulzer Orthopedics/Zimmer, Winterthur, Switzerland	New Zealand	125
Mueller	26	DePuy International, Leeds, U.K.	U.S.	141
PCA Pegged	23	Howmedica, East Rutherford, NJ	Finland	122
Romanus	23	Biomet	Finland	114
Spectron	64	Not specified	Norway	2019
T-28	41	Zimmer	U.S.	132
T-28	26	Zimmer	U.S.	559
Titan	64	Not specified	Norway	3205
Trabecular Metal Monoblock Acetabular Component System	68	Zimmer	Greece	156
Universal	23	Biomet	Finland	898
Universal	42	Biomet	U.S.	123
Weber Hemispheric	69	Hoechst, Germany	Netherlands	315
Zweymüller-Alloclassic Screw Cup	71	Zimmer, formerly Sulzer-medica, Winterthur, Switzerland	Netherlands	135
Zweymüller-Alloclassic Screw Cup	70	Sulzer Orthopedics/Zimmer, Winterthur, Switzerland	France	200

TABLE IV Characteristics of Studies Describing Survival Probabilities of Femoral Stems with Revision for Aseptic Loosening as the End Point

Stem	Ref.	Manufacturer	Country of Study Origin	No. at Baseline
ABG I	23	Stryker	Finland	390
ABG I	22	Howmedica, East Rutherford, NJ	U.K.	100
Anatomic Mesh	23	Zimmer, Warsaw, IN	Finland	135
Bi-Metric	46	Biomet	Sweden	104
Bi-Metric	23	Biomet	Finland	1982
Bi-Metric	47	Biomet	U.S.	105
Charnley	72	Thackray, DePuy, Leeds, U.K.	Japan	405
Charnley	64	Not specified	Norway	14,842
Charnley	48	Johnson & Johnson	U.S.	160
Charnley Elite-Plus	74	DePuy/Johnson & Johnson, Warsaw, IN	Sweden	114
Charnley Elite-Plus	73	Johnson & Johnson	Finland	885
Charnley Flat-back	73	Johnson & Johnson	Finland	925
CLS Spotorno	23	Sulzer-medica, Winterthur, Switzerland	Finland	108
Corail	49	DePuy, France	France	120
Exeter	64	Not specified	Norway	3934
Exeter Matt	73	Stryker	Finland	876
Exeter Universal	73	Stryker	Finland	10,620
Exeter Universal	50	Howmedica, East Rutherford, NJ	U.K.	230
Exeter Universal	75	Howmedica, East Rutherford, NJ	U.K.	142
Freeman Cemented	77	Finsbury Instruments, Leatherhead, U.K.	U.K.	92
Freeman Cemented	77	Finsbury Instruments, Leatherhead, U.K.	U.K.	97
Freeman Cemented	76	Finsbury Instruments, Leatherhead, U.K.	Australia	202
Freeman Cementless	78	Finsbury Instruments, Leatherhead, U.K.	U.K.	100
Freeman Cementless	51	Finsbury Instruments, Leatherhead, U.K.	U.K.	100
Furlong	33	Joint Replacement Instrumentation, London, U.K.	U.K.	134
Harris Design-2	66	Howmedica, East Rutherford, NJ	Canada	195
Harvard Femoral Stem	52	Harvard Health Care, Wakefield, West Yorkshire, U.K.	U.K.	269
Interlok	73	Biomet, Warsaw, IN	Finland	581
ITH	64	Not specified	Norway	2019
Lord Madreporique	23	Benoist Girard, Bagneux, France	Finland	286
Lord Madreporique	54	Benoist Girard, Bagneux, France	Norway	116
Lubinus IP	73	Link, Hamburg, Germany	Finland	5790
Lubinus SP II	73	Link, Hamburg, Germany	Finland	10,634
Mallory-Head Cementless	57	Biomet, Warsaw, IN	U.S.	2000
Mallory-Head Cementless	35	Biomet	Canada	307
MS-30	37	Zimmer, Warsaw, IN	Switzerland	124
Müller Straight Protasul-10 Cobalt-Nickel-Chromium	73	Zimmer, Warsaw, IN	Finland	2309
Müller Straight Protasul-10 Cobalt-Nickel-Chromium	79	Protek, Berne, Switzerland	Switzerland	112
Müller Straight Protasul-10 Cobalt-Nickel-Chromium	80	Not specified	Switzerland	161
Müller Style Titanium	81	Protek, Freiburg, Germany	Germany	203
Müller Style Titanium	82	Lima, Udine, Italy	Slovenia	170

continued

TABLE IV (*continued*)

Stem	Ref.	Manufacturer	Country of Study Origin	No. at Baseline
Omnifit Cemented	48	Osteonics, Allendale, NJ	U.S.	305
Osteonics Cemented	83	Osteonics, Allendale, NJ	U.S.	215
Osteonics Cementless	58	Stryker	U.S.	262
PCA	23	Howmedica, East Rutherford, NJ	Finland	111
Profile Porous	23	DePuy International, Leeds, U.K.	Finland	115
R-B Interlok	48	Biomet	U.S.	235
SBG	59	Plus Orthopaedics, Rotkreuz, Switzerland	Austria	230
Stanmore Custom Made	60	DePuy International, Leeds, U.K.	Italy	129
Taperloc	42	Biomet	U.S.	123
Taperloc	61	Biomet	U.S.	129
Titan	64	Not specified	Norway	3205
Zweymüller-Alloclassic	70	Sulzer-medica, Winterthur, Switzerland	France	200

the probability of revision surgery for each total hip implant with the NICE benchmark.

Materials and Methods

Protocol and registration: This systematic review and meta-analysis was performed from March 2011 to February 2013, with use of the guidelines of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Statement for development of the study protocol and reporting of the results of our study[12].

Eligibility criteria: The NICE Technology Appraisal Guidance states: "The evidence used in support of any prosthesis. . .should relate to data on 10 or more years follow up from a number of centres, obtained via adequately sized, well conducted observational studies (preferably with consecutive patients from non-selected populations) or randomised controlled trials. Such evidence should have been published or be available for peer review."[11]. Studies in which the authors reported the survival probability (i.e., the Kaplan-Meier estimate) for either the acetabular or the femoral component of a primary total hip replacement with use of revision for any reason or for aseptic loosening at ten years as the end point were eligible for inclusion. We considered studies to be of adequate size when there were at least 100 implants at baseline, and we defined a study population as representative of the general population at large when at least 60% of the patients had primary osteoarthritis. Studies with fewer than 100 implants at baseline and in which <60% of the patients had primary osteoarthritis were excluded. Studies were also excluded when the authors described the outcomes of multiple (sub)types of implants without reporting the outcomes for each (sub)type separately. Articles written in any language other than English, Dutch, German, French, Spanish, or Italian were not eligible for inclusion. In order to limit the extent of publication bias, no publication status restrictions were imposed.

Information sources: On March 22, 2011, an experienced independent information specialist (J.W.S.) searched four electronic databases: PubMed, Embase, Web of Science, and the Cochrane Library. We also performed implant-specific PubMed searches for all primary total hip replacement implants registered in the first annual report of the Dutch Arthroplasty Register (Landelijke Registratie Orthopedische Implantaten [LROI])[13]. Finally, national joint registries that were full members of the International Society of Arthroplasty Registers (ISAR; www.isarhome.org) were hand searched.

Search strategy: The following search terms were applied to PubMed and adapted for all other databases: (tha[tw] OR "total hip" OR "total hips" OR (("total joint" OR "total joints") AND (hips OR hip)) OR (total hip AND (prosthesis OR prosthetic OR endoprosthesis OR endoprostheses OR endoprosthetic OR arthroplasty OR arthroplasties OR replacement [tiab])) OR (Hip Replacement Arthroplasty AND total [tiab]) OR Hip Replacement Arthroplasty OR hip arthroplasty OR hip replacement OR Hip Prosthesis) AND (Osteoarthritis OR Osteoarthritides OR osteoarthriti* OR Osteoarthrosis[tiab] OR Osteoarthroses OR arthrosis[tw] OR arthroses OR "Degenerative Arthritis") NOT (early[tw] OR initial[tw] OR preliminary[tw] OR "short follow-up"[tw] OR "Letter"[Publication type] OR "Case Reports"[Publication Type]).

Study selection: Two authors (J.F.M. and S.D.M.) independently screened the titles and abstracts of the search results using prespecified eligibility criteria, as stated above. Two other authors (J.C.K. and F.R.V.T.) screened the full text of the remaining articles using the same eligibility criteria. Disagreements between authors were resolved by consensus.

Data collection process and data items: Data collection was performed by two authors (J.C.K. and F.R.V.T.) independently using predefined data extraction sheets. Inconsistencies between the two authors were resolved by consensus. When data were not reported numerically but were presented graphically in Kaplan-Meier curves, the estimated observations of both authors were averaged. The brand name and manufacturer of the implant, the Kaplan-Meier estimate at ten years, and its standard error and 95% confidence interval were extracted from each included study.

Risk of bias in individual studies: The methodological quality of all included studies was assessed with use of the Assessment of Quality in Lower Limb Arthroplasty (AQUILA) checklist, a tool specifically designed to appraise the quality of observational studies concerning total hip replacement and total knee replacement[14]. Two authors (J.C.K. and F.R.V.T.) independently assessed the quality of all included studies using predefined data-extraction sheets. Inconsistencies between the two authors were resolved by consensus.

Summary measures and synthesis of results: The principal summary measure was the survival probability for each implant at ten years with use of revision for any reason as the end point. The secondary summary measure was the survival probability for each implant at ten years with use of revision for aseptic loosening as the end point. Estimates of the survival probabilities in different studies on the same implant were pooled with use of inverse variance weighting. When no estimate of the variance or standard error of the survival probability at ten years was presented, we deduced the missing standard error from the confidence interval of the survival probability. When the study did not provide an estimate of the variance or standard error, or a confidence interval, we imputed the missing standard error from the mean standard error of all other studies[15,16]. When >50% of all standard errors were missing, we imputed the missing standard errors with single imputation on the basis of the survival estimate and the numbers of implants at baseline. We chose this approach instead of a more elaborate modeling approach[17-19] for two reasons. First, we

TABLE V Methodological Quality of Studies Describing Survival Probabilities of Acetabular Cups with Revision for Any Reason as the End Point

Cup	Ref.	Primary Research Question Stated	Cohort Construction	Adequacy of Follow-up	Follow-up Performed	No. at Risk at Follow-up	Worst-Case or Competing-Risk Analysis?
ABG I	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
ABG I	22	Yes	Unknown	Complete	Predefined	<20	Yes
ABG II HA	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
ACS Triloc+	24	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Arthopor	24	Yes	Non-consecutive	Unknown	Unknown	≥20	No
ATLAS II	25	Yes	Non-consecutive	>5% lost	Unknown	Unknown	No
ATLAS III	25	Yes	Non-consecutive	>5% lost	Unknown	Unknown	No
Charnley	26	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Charnley	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Charnley Elite	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
CLS Spotorno	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Conserve Plus	27	No	Non-consecutive	5% lost	Predefined	≥20	No
Exeter All-Polyethylene	28	Yes	Unknown	≤5% lost	Predefined	≥20	Yes
Exeter Duration	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Fitmore	29	Yes	Non-consecutive	≤5% lost	Not predefined	≥20	No
Harris Design-2	30	Yes	Consecutive	>5% lost	Predefined	≥20	No
Harris-Galante I	31	Yes	Non-consecutive	≤5% lost	Unknown	≥20	No
Harris-Galante II	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Hofer-Imhof	32	Yes	Unknown	>5% lost	Predefined	≥20	No
JRI Threaded Cup	33	Yes	Consecutive	>5% lost	Predefined	≥20	Yes
Lubinus	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Lubinus Eccentric	34	Yes	Unknown	Complete	Not predefined	≥20	No
Mallory-Head Cementless	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Mallory-Head Cementless	35	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
Miami Orthopaedic Surgical Clinic: All Polyethylene	26	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Miami Orthopaedic Surgical Clinic: Metal Backed	26	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Morscher Press Fit	37	No	Non-consecutive	Complete	Predefined	≥20	No
Morscher Press Fit	36	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
Mueller	26	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Novae	38	Yes	Non-consecutive	≤5% lost	Unknown	≥20	No
PCA Pegged	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Plasmacup	39	Yes	Non-consecutive	>5% lost	Not predefined	≥20	No
RM	40	Yes	Unknown	≤5% lost	Unknown	Unknown	Yes
Romanus	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
T-28	26	Yes	Non-consecutive	Unknown	Unknown	≥20	No
T-28	41	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
Trilogy HA	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Universal	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Universal	42	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
Zweymüller-Alloclassic Screw Cup	44	Yes	Non-consecutive	>5% lost	Not predefined	≥20	No
Zweymüller-Alloclassic Screw Cup	43	No	Unknown	≤5% lost	Unknown	≥20	No

TABLE VI Methodological Quality of Studies Describing Survival Probabilities of Femoral Stems with Revision for Any Reason as the End Point

Cup	Ref.	Primary Research Question Stated	Cohort Construction	Adequacy of Follow-up	Follow-up Performed	No. at Risk at Follow-up	Worst-Case or Competing-Risk Analysis?
ABG I	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
ABG I	22	Yes	Unknown	Complete	Predefined	<20	Yes
ABG I	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Anatomic Mesh	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Bicontact	45	Yes	Unknown	≤5% lost	Not predefined	≥20	No
Bi-Metric	46	Yes	Unknown	≤5% lost	Not predefined	≥20	No
Bi-Metric	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Bi-Metric	47	Yes	Unknown	≤5% lost	Predefined	≥20	Yes
Charnley	48	Yes	Consecutive	>5% lost	Not predefined	≥20	Yes
Charnley	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
CLS Spotorno	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
CLS Spotorno	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Conserve Plus	27	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
Corail	49	Yes	Unknown	≤5% lost	Not predefined	≥20	No
Exeter Polished	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Exeter Universal	50	Yes	Unknown	≤5% lost	Predefined	≥20	Yes
Freeman Cementless	51	Yes	Unknown	>5% lost	Predefined	≥20	Yes
Furlong	33	Yes	Consecutive	≤5% lost	Predefined	≥20	Yes
Harvard Femoral Stem	52	Yes	Unknown	≤5% lost	Not predefined	≥20	No
Heritage	53	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Iowa polished	53	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Lord Madreporique	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Lord Madreporique	54	Yes	Consecutive	≤5% lost	Not predefined	≥20	No
Lubinus IP	55	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
Lubinus IP	34	Yes	Non-consecutive	Complete	Not predefined	≥20	No
Lubinus SP	55	Yes	Non-consecutive	>5% lost	Predefined	≥20	No
Lubinus SP	34	Yes	Non-consecutive	Complete	Not predefined	≥20	No
Lubinus SP II	21	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Mallory-Head Cemented	56	Yes	Non-consecutive	≤5% lost	Not predefined	≥20	No
Mallory-Head Cementless	57	Yes	Unknown	>5% lost	Not predefined	≥20	No
Mallory-Head Cementless	35	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
MS-30	37	Yes	Unknown	Complete	Predefined	≥20	No
Omnifit Cemented	48	Yes	Non-consecutive	>5% lost	Not predefined	≥20	Yes
Osteonics Cementless	58	Yes	Unknown	Unknown	Not predefined	≥20	No
PCA	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Profile Porous	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
R-B Interlok	48	Yes	Non-consecutive	>5% lost	Not predefined	≥20	Yes
SBG	59	Yes	Unknown	>5% lost	Not predefined	≥20	No
Stanmore Custom Made	60	Yes	Non-consecutive	Complete	Predefined	≥20	No
Taperloc	61	Yes	Unknown	≤5% lost	Predefined	≥20	Yes
Triumph	53	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Zweymüller SL	44	Yes	Non-consecutive	>5% lost	Not predefined	≥20	No

TABLE VII Methodological Quality of Studies Describing Survival Probabilities of Acetabular Cups with Revision for Aseptic Loosening as the End Point

Cup	Ref.	Primary Research Question Stated	Cohort Construction	Adequacy of Follow-up	Follow-up Performed	No. at Risk at Follow-up	Worst-Case or Competing-Risk Analysis?
ABG I	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
ACS Triloc+	24	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Arthopor	24	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Brunswik	62	Yes	Non-consecutive	Complete	Not predefined	≥20	No
Charnley	63	No	Consecutive	≤5% lost	Not predefined	≥20	No
Charnley	62	Yes	Non-consecutive	Complete	Not predefined	≥20	No
Charnley	64	Yes	Non-consecutive	≤5% lost	Not predefined	≥20	No
Charnley	26	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Charnley All-Polyethylene	65	No	Non-consecutive	>5% lost	Unknown	≥20	No
Conserve Plus	27	No	Non-consecutive	≤5% lost	Predefined	≥20	No
Elite Ogee	50	No	Non-consecutive	≤5% lost	Unknown	Unknown	Yes
Exeter	64	Yes	Non-consecutive	≤5% lost	Not predefined	≥20	No
Exeter All-Polyethylene	28	Yes	Unknown	≤5% lost	Predefined	≥20	Yes
Fitmore	29	Yes	Non-consecutive	≤5% lost	Not predefined	≥20	No
Harris Design-2 All-Polyethylene	66	Yes	Unknown	≤5% lost	Predefined	≥20	No
Harris-Galante II	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Hofer-Imhof	67	Yes	Non-consecutive	Complete	Predefined	≥20	No
Hofer-Imhof	32	Yes	Unknown	>5% lost	Predefined	≥20	No
JRI Threaded Cup	33	Yes	Consecutive	>5% lost	Predefined	≥20	Yes
Link	64	Yes	Non-consecutive	≤5% lost	Not predefined	≥20	No
Lord Threaded	54	Yes	Consecutive	Unknown	Predefined	≥20	Yes
Mallory-Head Cementless	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Miami Orthopaedic Surgical Clinic: All Polyethylene	26	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Miami Orthopaedic Surgical Clinic: Metal Backed	26	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Morscher Press Fit	37	No	Non-consecutive	Complete	Predefined	≥20	No
Morscher Press Fit	36	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
Mueller	26	Yes	Non-consecutive	Unknown	Unknown	≥20	No
PCA Pegged	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Romanus	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Spectron	64	Yes	Non-consecutive	≤5% lost	Not predefined	≥20	No
T-28	41	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
T-28	26	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Titan	64	Yes	Non-consecutive	≤5% lost	Not predefined	≥20	No
Trabecular Metal Monoblock Acetabular Component System	68	Yes	Non-consecutive	Complete	Not predefined	≥20	No
Universal	23	Yes	Non-consecutive	Unknown	Unknown	≥20	No
Universal	42	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
Weber Hemispheric	69	Yes	Unknown	>5% lost	Unknown	≥20	Yes
Zweymüller-Alloclassic Screw Cup	71	Yes	Unknown	≤5% lost	Predefined	≥20	Yes
Zweymüller-Alloclassic Screw Cup	70	Yes	Non-consecutive	Unknown	Predefined	≥20	Yes

TABLE VIII Methodological Quality of Studies Describing Survival Probabilities of Femoral Stems with Revision for Aseptic Loosening as the End Point

Cup	Ref.	Primary Research Question Stated	Cohort Construction	Adequacy of Follow-up	Follow-up Performed	No. at Risk at Follow-up	Worst-Case or Competing-Risk Analysis?
ABG I	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
ABG I	22	Yes	Unknown	Complete	Predefined	<20	Yes
Anatomic Mesh	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Bi-Metric	46	Yes	Unknown	≤5% lost	Not predefined	≥20	No
Bi-Metric	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Bi-Metric	47	Yes	Unknown	≤5% lost	Predefined	≥20	Yes
Charnley	72	No	Unknown	Unknown	Not predefined	≥20	No
Charnley	64	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Charnley	48	Yes	Consecutive	>5% lost	Not predefined	≥20	No
Charnley Elite-Plus	74	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Charnley Elite-Plus	73	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Charnley Flat-back	73	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
CLS Spotorno	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Corail	49	Yes	Unknown	≤5% lost	Not predefined	≥20	No
Exeter	64	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Exeter Matt	73	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Exeter Universal	73	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Exeter Universal	50	Yes	Unknown	≤5% lost	Predefined	≥20	Yes
Exeter Universal	75	Yes	Unknown	Complete	Not predefined	≥20	No
Freeman Cemented	77	No	Unknown	≤5% lost	Predefined	≥20	No
Freeman Cemented	77	No	Unknown	≤5% lost	Predefined	≥20	No
Freeman Cemented	76	Yes	Unknown	≤5% lost	Not predefined	<20	No
Freeman Cementless	78	Yes	Unknown	≤5% lost	Predefined	≥20	Yes
Freeman Cementless	51	Yes	Unknown	>5% lost	Predefined	≥20	Yes
Furlong	33	Yes	Consecutive	≤5% lost	Predefined	≥20	No
Harris Design-2	66	Yes	Unknown	≤5% lost	Predefined	≥20	No
Harvard Femoral Stem	52	Yes	Unknown	≤5% lost	Not predefined	≥20	No
Interlok	73	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
ITH	64	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Lord Madreporique	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Lord Madreporique	54	Yes	Consecutive	≤5% lost	Not predefined	≥20	No
Lubinus IP	73	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Lubinus SP II	73	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Mallory-Head Cementless	57	Yes	Unknown	>5% lost	Not predefined	≥20	No
Mallory-Head Cementless	35	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
MS-30	37	Yes	Unknown	Complete	Predefined	≥20	No
Müller Straight Protasul-10 Cobalt-Nickel-Chromium	73	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Müller Straight Protasul-10 Cobalt-Nickel-Chromium	79	Yes	Non-consecutive	≤5% lost	Not predefined	≥20	No
Müller Straight Protasul-10 Cobalt-Nickel-Chromium	80	Yes	Unknown	≤5% lost	Predefined	≥20	No
Müller Style Titanium	81	Yes	Non-consecutive	>5% lost	Not predefined	≥20	No
Müller Style Titanium	82	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No

continued

TABLE VIII (*continued*)

Cup	Ref.	Primary Research Question Stated	Cohort Construction	Adequacy of Follow-up	Follow-up Performed	No. at Risk at Follow-up	Worst-Case or Competing-Risk Analysis?
Omnifit Cemented	48	Yes	Consecutive	>5% lost	Not predefined	≥20	No
Osteonics Cemented	83	Yes	Consecutive	>5% lost	Not predefined	≥20	No
Osteonics Cementless	58	Yes	Unknown	Unknown	Not predefined	≥20	No
PCA	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
Profile Porous	23	Yes	Non-consecutive	Unknown	Not predefined	≥20	No
R-B Interlok	48	Yes	Consecutive	>5% lost	Not predefined	≥20	No
SBG	59	Yes	Unknown	>5% lost	Not predefined	≥20	No
Stanmore Custom Made	60	Yes	Non-consecutive	Complete	Predefined	≥20	No
Taperloc	42	Yes	Non-consecutive	≤5% lost	Predefined	≥20	No
Taperloc	61	Yes	Unknown	≤5% lost	Predefined	≥20	Yes
Titan	64	Yes	Non-consecutive	Unknown	Predefined	≥20	No
Zweymüller-Alloclassic	70	Yes	Non-consecutive	Unknown	Predefined	≥20	Yes

were interested in the survival probability at only one specific point in time. Second, the majority of studies that did not provide the standard error also did not give enough information to allow modeling of the survival probability. In order to test whether each implant performed better than the NICE benchmark, we calculated the confidence interval for each implant survival estimate. The ten-year revision rate of 10% for a total hip implant corresponds with a survival probability of 90% for a total hip implant. Therefore, the survival probability of a cup or stem should exceed 90%. Assuming independence of the survival probability for either the cup or the stem, we can summarize the minimal survival probability with the formula: $p_{cup} * p_{stem} \geq 0.9$. When it is assumed that $p_{cup} = p_{stem}$, then the minimal survival probability for the cup is $p_{cup}^2 = 0.9$, leading to a minimal cup survival probability of $\sqrt{0.9}$, which is rounded to 95%. Therefore, the survival probability of either the cup or the stem should exceed 95%. When both the survival estimate and the lower limit of the confidence interval were >95%, we concluded that that particular implant performed significantly better than the NICE benchmark. When both the survival estimate and the upper limit of the confidence interval were <95%, we concluded that that particular implant performed significantly worse than the NICE benchmark. In all other cases, we concluded that there was insufficient evidence to suggest that the particular implant performed better or worse than the NICE benchmark.

All analyses were performed with use of R version 2.15.2[20].

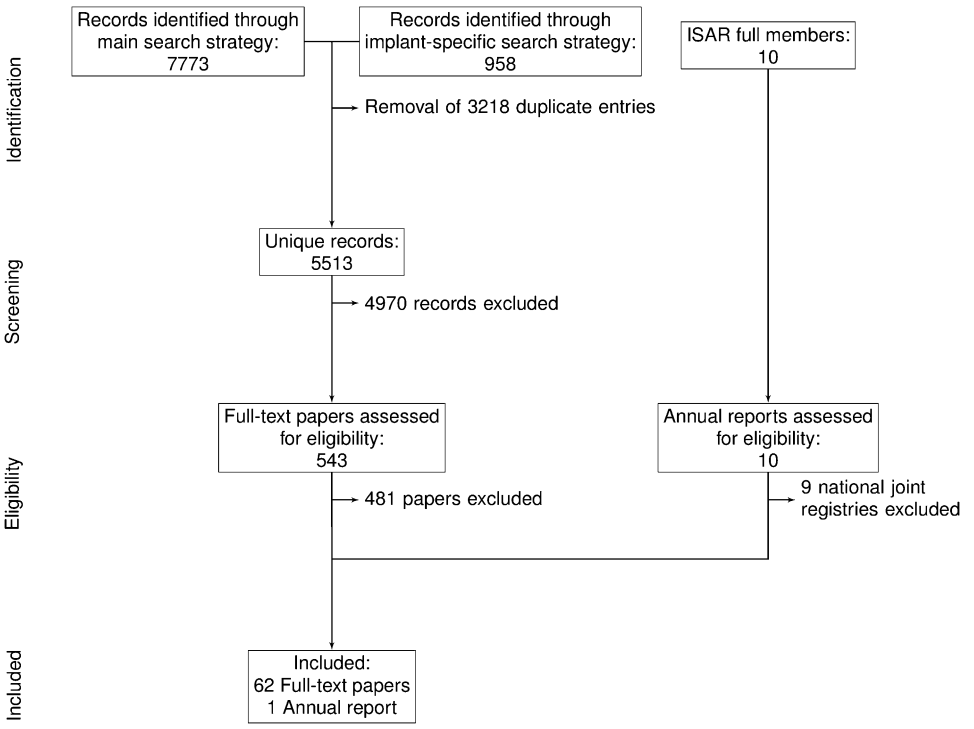

Fig. 1

Flow-chart of study inclusion.

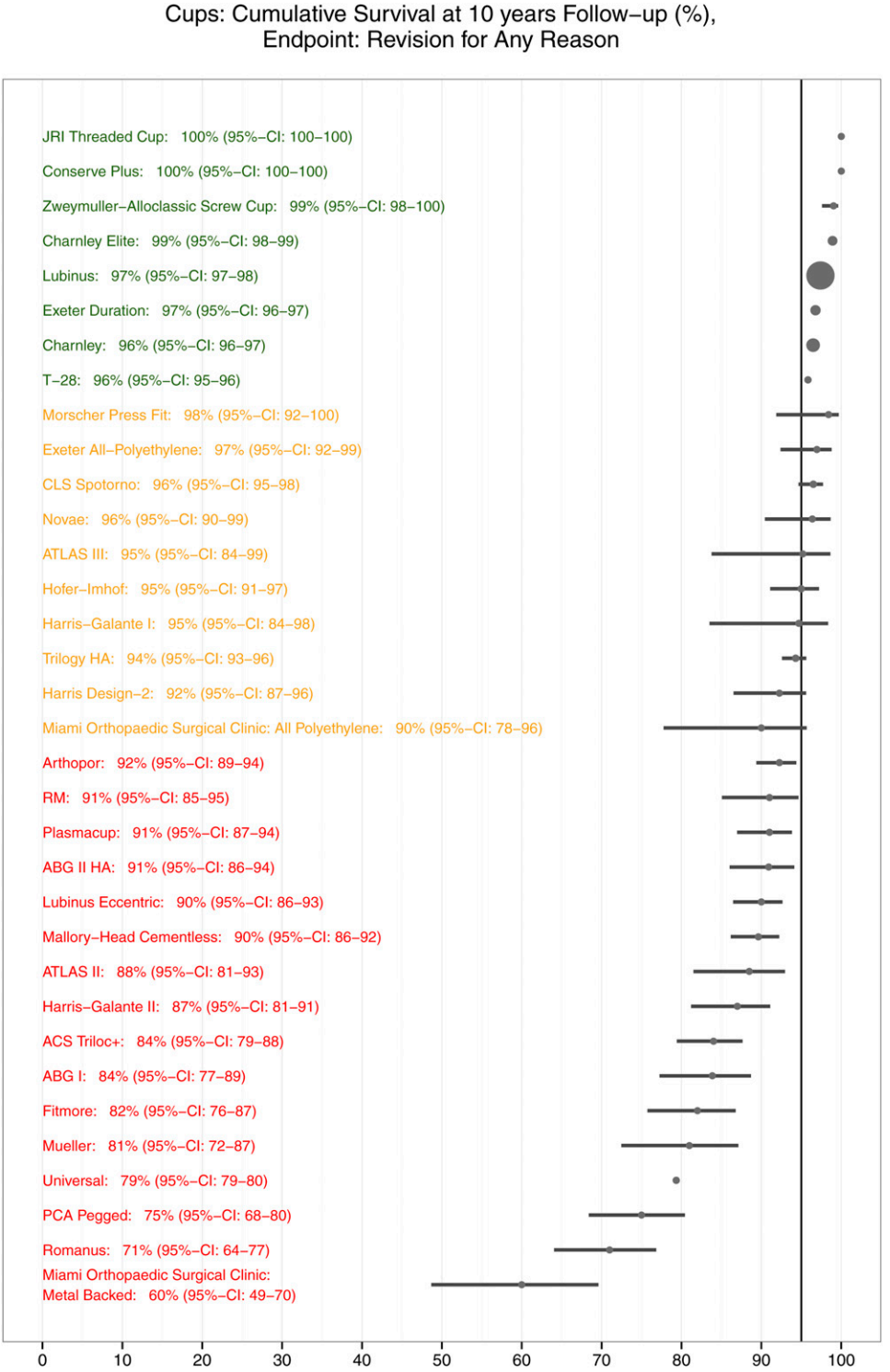

Fig. 2

Cumulative survival (and 95% confidence interval [CI]) of acetabular cups at ten years with use of revision for any reason as the end point. The vertical line indicates the NICE benchmark. The color of the text indicates whether an implant performs significantly better (green) or worse (red) than the NICE benchmark or whether there was insufficient evidence to make this determination (yellow). The size of the points indicates the sample size on which the estimates are based.

Source of funding: This study was funded by a grant from the Dutch Arthritis Association (Grant number LLP-13), which had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all of the data in the study. All authors had final responsibility for the decision to submit for publication.

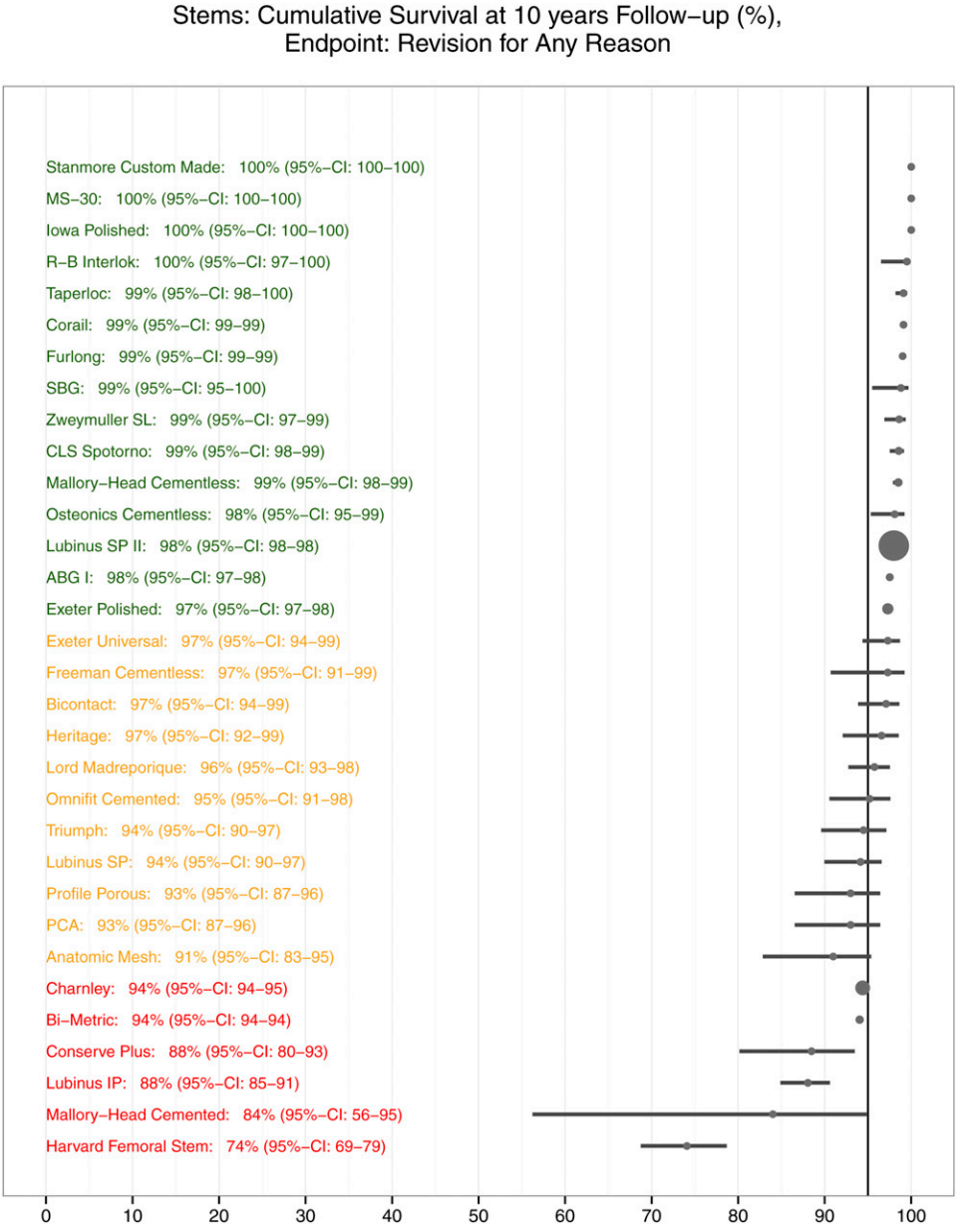

Fig. 3

Cumulative survival (and 95% confidence interval [CI]) of femoral stems at ten years with use of revision for any reason as the end point. The vertical line indicates the NICE benchmark. The color of the text indicates whether an implant performs significantly better (green) or worse (red) than the NICE benchmark or whether there was insufficient evidence to make this determination (yellow). The size of the points indicates the sample size on which the estimates are based.

Results

Study selection: Our search strategy revealed 8731 hits: the main search strategy yielded 7773 hits, and the implant-specific search yielded an additional 958 hits (Fig. 1). After removal of duplicate entries, 5513 unique papers remained, and their titles and abstracts were screened; 4970 papers were excluded, leaving 543 papers eligible for inclusion. Further assessment of eligibility based on the full-text papers led to the exclusion of 481 papers: 259 papers did not report the survival probability of a cup or stem at ten years, and 222 papers did not provide separate results for cups or stems. This left sixty-three papers for further analysis. Of all national joint registries that were full members of ISAR, only the Swedish Hip Arthroplasty Register reported separate results for cups and stems at ten years with revision for any reason as the end point[21].

Study characteristics and risk of bias: Tables I and II provide an overview of the characteristics of all included studies in which the end point was revision for any reason, and Tables III and IV provide such an overview for the studies in which the end point was revision for aseptic loosening. The methodological quality of the studies in which revision for any reason was the end

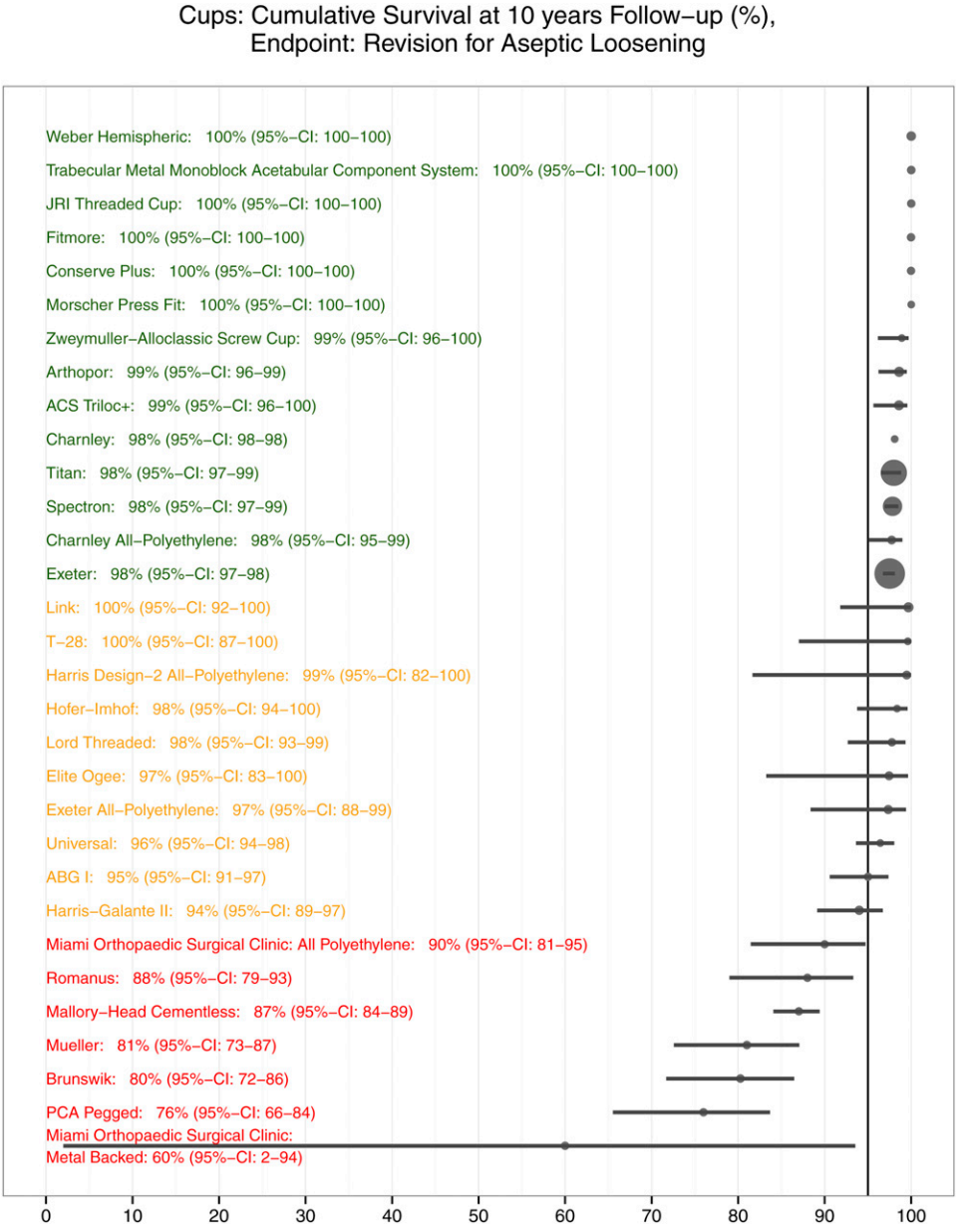

Fig. 4

Cumulative survival (and 95% confidence interval [CI]) of acetabular cups at ten years with use of revision for aseptic loosening as the end point. The vertical line indicates the NICE benchmark. The color of the text indicates whether an implant performs significantly better (green) or worse (red) than the NICE benchmark or whether there was insufficient evidence to make this determination (yellow). The size of the points indicates the sample size on which the estimates are based.

point is shown in Tables V and VI, and the methodological quality of the studies in which the end point was revision for aseptic loosening is shown in Tables VII and VIII.

We found forty-one cohorts for which the ten-year survival probability of an acetabular cup was described with revision for any reason as the end point. These studies included a total of thirty-four different acetabular implants: ABG I[22,23], ABG II HA[21], ACS Triloc+[24], Arthopor[24], ATLAS II[25], ATLAS III[25], Charnley[21,26], Charnley Elite[21], CLS Spotorno[21], Conserve Plus[27], Exeter All-Polyethylene[28], Exeter Duration[21], Fitmore[29], Harris Design-2[30], Harris-Galante I[31], Harris-Galante II[23], Hofer-Imhof[32], JRI Threaded Cup[33], Lubinus[21], Lubinus Eccentric[34], Mallory-Head Cementless[23,35], Miami Orthopaedic Surgical Clinic: All Polyethylene[26], Miami Orthopaedic Surgical Clinic: Metal Backed[26], Morscher Press Fit[36,37], Mueller[26], Novae[38], PCA Pegged[23], Plasmacup[39], RM[40], Romanus[23], T-28[26,41], Trilogy HA[21], Universal[23,42], and Zweymüller-Alloclassic Screw Cup[43,44].

Forty-two papers described the ten-year survival probability of thirty-two different femoral stem implants with revision for any reason as the end point: ABG I[21-23], Anatomic Mesh[23], Bicontact[45], Bi-Metric[23,46,47], Charnley[21,48], CLS Spotorno[21,23],

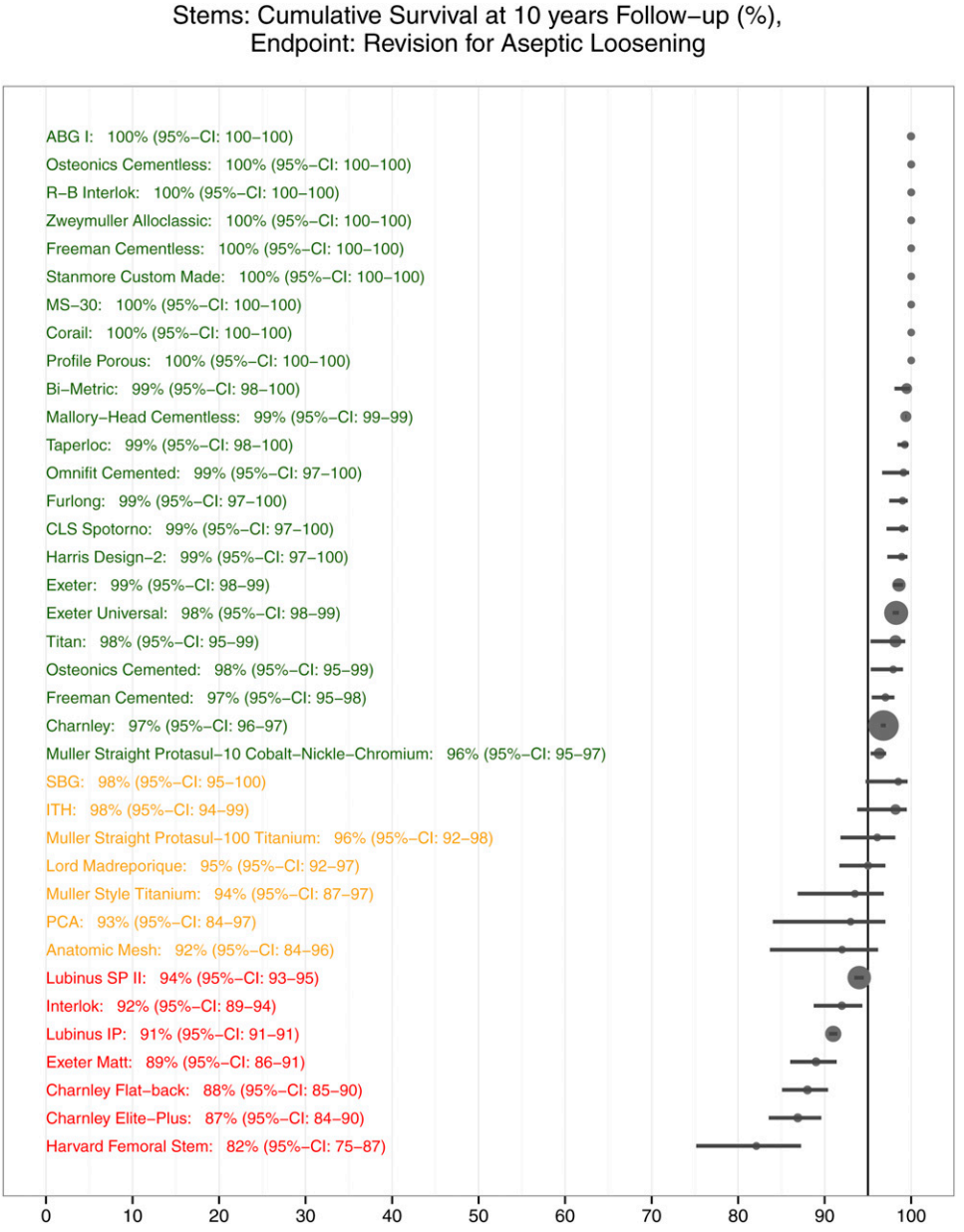

Fig. 5

Cumulative survival (and 95% confidence interval [CI]) of femoral stems at ten years with use of revision for aseptic loosening as the end point. The vertical line indicates the NICE benchmark. The color of the text indicates whether an implant performs significantly better (green) or worse (red) than the NICE benchmark or whether there was insufficient evidence to make this determination (yellow). The size of the points indicates the sample size on which the estimates are based.

Conserve Plus[27], Corail[49], Exeter Polished[21], Exeter Universal[50], Freeman Cementless[51], Furlong[33], Harvard Femoral Stem[52], Heritage[53], Iowa polished[53], Lord Madreporique[23,54], Lubinus IP[34,55], Lubinus SP[34,55], Lubinus SP II[21], Mallory-Head Cemented[56], Mallory-Head Cementless[35,57], MS-30[37], Omnifit Cemented[48], Osteonics Cementless[58], PCA[23], Profile Porous[23], R-B Interlok[48], SBG[59], Stanmore Custom Made[60], Taperloc[61], Triumph[53], and Zweymüller SL[44].

Thirty-nine papers described the ten-year survival probability of thirty-one different acetabular cup implants with revision for aseptic loosening as the end point: ABG I[23], ACS Triloc+[24], Arthopor[24], Brunswik[62], Charnley[26,62-64], Charnley All-Polyethylene[65], Conserve Plus[27], Elite Ogee[50], Exeter[64], Exeter All-Polyethylene[28], Fitmore[29], Harris Design-2 All-Polyethylene[66], Harris-Galante II[23], Hofer-Imhof[32,67], JRI Threaded Cup[33], Link[64], Lord Threaded[54], Mallory-Head Cementless[23], Miami Orthopaedic Surgical Clinic: All Polyethylene[26], Miami Orthopaedic Surgical Clinic: Metal Backed[26], Morscher Press Fit[36,37], Mueller[26], PCA Pegged[23], Romanus[23], Spectron[64], T-28[26,41], Titan[64], Trabecular Metal Monoblock Acetabular Component

System[68], Universal[23,42], Weber Hemispheric[69], and Zweymüller-Alloclassic Screw Cup[70,71].

Finally, we found fifty-two cohorts in which the ten-year survival probability of thirty-seven different femoral stem implants was assessed with revision for aseptic loosening as the end point: ABG I[22,23], Anatomic Mesh[23], Bi-Metric[23,46,47], Charnley[48,64,72], Charnley Elite-Plus[73,74], Charnley Flat-back[73], CLS Spotorno[23], Corail[49], Exeter[64], Exeter Matt[73], Exeter Universal[50,73,75], Freeman Cemented[76,77], Freeman Cementless[51,78], Furlong[33], Harris Design-2[66], Harvard Femoral Stem[52], Interlok[73], ITH[64], Lord Madreporique[23,54], Lubinus IP[73], Lubinus SP II[73], Mallory-Head Cementless[35,57], MS-30[37], Müller Straight Protasul-10 Cobalt-Nickel-Chromium[73,79,80], Müller Straight Protasul-100 Titanium[81], Müller Style Titanium[82], Omnifit Cemented[48], Osteonics Cemented[83], Osteonics Cementless[58], PCA[23], Profile Porous[23], R-B Interlok[48], SBG[59], Stanmore Custom Made[60], Taperloc[42,61], Titan[64], and Zweymüller-Alloclassic[70].

Synthesis of results: An overview of the survival probabilities for the different implants is presented in Figures 2 through 5. With use of revision for any reason as the end point, the following acetabular cups performed better than the NICE benchmark: JRI Threaded Cup, Conserve Plus, Zweymüller-Alloclassic Screw Cup, Charnley Elite, Lubinus, Exeter Duration, Charnley, and T-28 (Fig. 2). With use of revision for any reason as the end point, the following femoral stems performed better than the NICE benchmark: Stanmore Custom Made, MS-30, Iowa polished, Ranawat-Burstein (R-B) Interlok, Taperloc, Corail, Furlong, SBG, Zweymüller SL, CLS Spotorno, Mallory-Head Cementless, Osteonics Cementless, Lubinus SP II, ABG I, and Exeter Polished (Fig. 3). With use of revision for aseptic loosening as the end point, the following acetabular cups performed better than the NICE benchmark: Weber Hemispheric, Trabecular Metal Monoblock Acetabular Component System, JRI Threaded Cup, Fitmore, Conserve Plus, Morscher Press Fit, Zweymüller-Alloclassic Screw Cup, Arthopor, ACS Triloc+, Charnley, Titan, Spectron, Charnley All-Polyethylene, and Exeter (Fig. 4). With use of revision for aseptic loosening as the end point, the following femoral stems performed better than the NICE benchmark: ABG I, Osteonics Cementless, R-B Interlok, Zweymüller-Alloclassic, Freeman Cementless, Stanmore Custom Made, MS-30, Corail, Profile Porous, Bi-Metric, Mallory-Head Cementless, Taperloc, Omnifit Cemented, Furlong, CLS Spotorno, Harris Design-2, Exeter, Exeter Universal, Titan, Osteonics Cemented, Freeman Cemented, Charnley, and Müller Straight Protasul-10 Cobalt-Nickle-Chromium (Fig. 5).

Discussion

In this systematic review and meta-analysis, we estimated the probability of revision surgery at ten years for thirty-four types of acetabular cups and thirty-two types of femoral stems that were available on the market with published results. Of these implants, eight acetabular cups and fifteen femoral stems performed better than the NICE benchmark. Most studies were of low methodological quality: the majority of studies consisted of non-consecutive cohorts, with more than 5% of the hips lost to follow-up and no worst-case analysis.

In the past decades, numerous efforts have been made to improve the survival probability of primary total hip implants. Some efforts, such as the addition of antibiotics to bone cement[84], have led to an improvement in survival probability. Others, such as the introduction of Boneloc cement or the 3M Capital Hip System, have led to unprecedented failures, which could have been prevented by phased introduction of new implants and techniques[85,86]. Despite subsequent calls for stricter regulation of new total hip implants[5,87], few actions were taken, facilitating the recent disaster with the ASR hip prosthesis[88]. In providing an overview of all implants that perform better or worse than the NICE benchmark, we aid practicing orthopaedic surgeons in choosing safe, time-proven implants for primary total hip replacement. Additionally, our study documents that an astonishingly limited number of publications are currently available.

There are a number of limitations to this study. The description of the type of implant used in a specific total hip replacement cohort was often limited to the specific brand name. Some studies, such as the well-described one by Franklin et al.[89], included the results of multiple subtypes of implants, which had undergone major changes in design, summarized in one survival estimate at ten years. We excluded studies that did not specify separate survival estimates for subtypes with substantial changes in design. In all other papers, we assumed that a single subtype of implant was used for all patients.

Additionally, the NICE benchmarks were poorly defined, leaving much room for interpretation[11]. The recommendation to use a ten-year revision rate of 10% as a threshold does not specify any particular end point—e.g., aseptic loosening or revision for any reason. Additionally, it is unclear whether this revision rate should include the acetabular or femoral component or both implants. Furthermore, no guidance is given regarding the statistical methods to use for outlier detection. Finally, the guidelines do not define "adequately sized" or "well conducted" studies. In order to err on the side of caution, we chose revision for any reason instead of revision for aseptic loosening as the primary outcome measure. Aseptic loosening is considered the principal mechanism of failure of total hip replacement at the time of long-term follow-up, and it is slowly progressive and causes disabling pain[90]. Especially in the case of focal osteolysis, an implant might appear solidly fixed at revision surgery, despite moving up to 1 mm relative to the surrounding bone[91]. In order to minimize the risk of misclassification bias (e.g., misclassifying cases of aseptic loosening as cases revised for persistent pain after joint replacement), we chose to use revision for any reason as the principal outcome measure[92]. On the basis of our clinical judgment, we defined the revision rate of 10% as referring to the combination of both implants and defined "adequately sized" as a minimum of 100 implants at baseline.

No competing-risk analyses were performed in any of the included cohorts. It is highly unlikely that no competing events, such as the death of a patient, have taken place within ten years after primary total hip replacement. Disregarding these competing events leads to an underestimation of the survival probability[93]. Therefore, some implants might outperform the NICE benchmark in reality but not appear to do so on the basis of their survival estimates because of unrealistic statistical assumptions.

In our analyses, we assumed that the case mix of all studies was similar. Regarding one of the most important characteristics—namely, the indication for joint replacement—this was certainly the case, as this was one of the inclusion criteria. Other characteristics, such as age, sex, physical activity, and number of comorbidities were not recorded and might have differed among the cohorts. Some patient characteristics, such as age and sex, are easily identified in most studies. Others, such as physical activity and number of comorbidities, are not uniformly measured if they are measured at all. Because there is no current consensus on relevant case-mix variables[14], we decided to omit these variables from this systematic review.

Finally, the majority of the survival estimates were based on a single study performed in a single center. This raises the question of whether the survival rates presented in this meta-analysis represent the actual survival rates of these implants. In the unlikely case of extreme publication bias, an implant might appear to outperform the NICE benchmark in the only published study while performing worse in the unpublished reality. Extreme negative publication bias is also theoretically possible. Surgeons who notice poor results using a certain prosthesis might be more inclined to report their results, as a general warning, than are surgeons who notice acceptable results. In the case of extreme negative publication bias, an implant might appear to perform worse than the NICE in the only published study while performing better in the unpublished reality. It is difficult to study the effect of publication bias in this meta-analysis. Conventional methods such as funnel plots would fail in this case, as it would be pointless to make a funnel plot for an implant for which there was only one estimate and therefore only one point. A sensible approach is to interpret estimates based on the experience at a single center with more caution, especially if those centers were involved in the design of the implant[94].

A wide variety of implants is available to orthopaedic surgeons worldwide, but there is a very limited amount of evidence for some of these implants. In the European Union, there is a single organization for the approval of drugs—the European Medicines Agency, which demands evidence of safety and efficacy in controlled trials. In contrast, for medical devices such as an orthopaedic implant, it is only necessary to obtain a European Conformity (Conformité Européene [CE]) mark, which requires limited or no evidence of clinical efficacy[95]. Since the introduction of Charnley's total hip replacement in the late 1950s, new successful total hip replacement implants have been designed, lowering the probability of revision surgery. However, recent problems with several hip prostheses have illustrated that patient safety can be at risk when new total hip replacement implants are developed[96,97]. We encourage the development of new implants but not at the cost of patient safety[98]. Therefore, the development of new implants should take place in the setting of comparative clinical studies. Ideally, results of experimental implants should be compared with results of implants that outperform the NICE benchmark. To provide access to innovative treatments while ensuring that evidence is collected, health-care funders need to implement a payment-with-evidence-development approach[99].

The use of optimally performing total hip implants is possible despite older and more recent disasters with certain hip implants. It is the surgeon who has to decide which implant will provide the best quality for his or her specific patient. The current study underscores that there is evidence in the literature, but that evidence has to be used. ■

J. Christiaan Keurentjes, MD
Bart G. Pijls, MD, PhD
Floris R. Van Tol, MSc
Jill F. Mentink, MD
Stephanie D. Mes, MD
Rob G. Nelissen, MD, PhD
Department of Orthopaedic Surgery,
Leiden University Medical Center,
Postbus 9600,
2300 RC Leiden,
Leiden, the Netherlands.
E-mail address for J.C. Keurentjes: j.c.keurentjes@lumc.nl

Jan W. Schoones, MSc
Walaeus Library,
Leiden University Medical Center,
Postbus 9600,
2300 RC Leiden,
Leiden, the Netherlands

Marta Fiocco, PhD
Department of Medical Statistics and BioInformatics,
Leiden University Medical Center,
Postbus 9600,
2300 RC Leiden,
Leiden, the Netherlands

Art Sedrakyan, MD, PhD
Weill Cornell Medical College,
402 East 67th Street,
New York, NY 10065

References

1. Ethgen O, Bruyère O, Richy F, Dardennes C, Reginster JY. Health-related quality of life in total hip and total knee arthroplasty. A qualitative and systematic review of the literature. J Bone Joint Surg Am. 2004 May;86(5):963-74.

2. Keurentjes JC, Blane D, Bartley M, Keurentjes JJ, Fiocco M, Nelissen RG. Socio-economic position has no effect on improvement in health-related quality of life and patient satisfaction in total hip and knee replacement: a cohort study. PLoS One. 2013;8(3):e56785. Epub 2013 Mar 8.

3. Keurentjes JC, Fiocco M, So-Osman C, Onstenk R, Koopman-Van Gemert AWMM, Pöll RG, Kroon HM, Vliet Vlieland TP, Nelissen RG. Patients with severe radiographic osteoarthritis have a better prognosis in physical functioning after hip and knee replacement: a cohort-study. PLoS One. 2013;8(4):e59500. Epub 2013 Apr 3.

4. Keurentjes JC, Fiocco M, Nelissen RG. Willingness to undergo surgery again validated clinically important differences in health-related quality of life after total hip replacement or total knee replacement surgery. J Clin Epidemiol. 2014 Jan;67(1):114-20. Epub 2013 Jul 10.

5. Murray DW, Carr AJ, Bulstrode CJ. Which primary total hip replacement? J Bone Joint Surg Br. 1995 Jul;77(4):520-7.

6. Bozic KJ, Durbhakula S, Berry DJ, Naessens JM, Rappaport K, Cisternas M, Saleh KJ, Rubash HE. Differences in patient and procedure characteristics and hospital resource use in primary and revision total joint arthroplasty: a multicenter study. J Arthroplasty. 2005 Oct;20(7)(Suppl 3):17-25.

7. Bozic KJ, Katz P, Cisternas M, Ono L, Ries MD, Showstack J. Hospital resource utilization for primary and revision total hip arthroplasty. J Bone Joint Surg Am. 2005 Mar;87(3):570-6.

8. Ong KL, Mowat FS, Chan N, Lau E, Halpern MT, Kurtz SM. Economic burden of revision hip and knee arthroplasty in Medicare enrollees. Clin Orthop Relat Res. 2006 May;446(446):22-8.

9. Vanhegan IS, Malik AK, Jayakumar P, Ul Islam S, Haddad FS. A financial analysis of revision hip arthroplasty: the economic burden in relation to the national tariff. J Bone Joint Surg Br. 2012 May;94(5):619-23.

10. Schreurs BW, Keurentjes JC, Gardeniers JWM, Verdonschot N, Slooff TJJH, Veth RP. Acetabular revision with impacted morsellised cancellous bone grafting and a cemented acetabular component: a 20- to 25-year follow-up. J Bone Joint Surg Br. 2009 Sep;91(9):1148-53.

11. National Institute for Health and Care Excellence. Review of TA2 hip disease replacement prostheses and TA44 hip disease metal on metal resurfacing. http://www.nice.org.uk/nicemedia/live/11386/54748/54748.pdf.

12. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009;339:b2535-2535. Epub 2009 Jul 21.

13. LROI. Annual reports. Insight into quality of orthopaedic care in the Netherlands. http://www.lroi.nl/en/annual-reports. Accessed 2014 May 7.

14. Pijls BG, Dekkers OM, Middeldorp S, Valstar ER, van der Heide HJL, Van der Linden-Van der Zwaag HM, Nelissen RG. AQUILA: assessment of quality in lower limb arthroplasty. An expert Delphi consensus for total knee and total hip arthroplasty. BMC Musculoskelet Disord. 2011;12:173. Epub 2011 Jul 22.

15. Thiessen Philbrook H, Barrowman N, Garg AX. Imputing variance estimates do not alter the conclusions of a meta-analysis with continuous outcomes: a case study of changes in renal function after living kidney donation. J Clin Epidemiol. 2007 Mar;60(3):228-40. Epub 2006 Oct 23.

16. Furukawa TA, Barbui C, Cipriani A, Brambilla P, Watanabe N. Imputing missing standard deviations in meta-analyses can provide accurate results. J Clin Epidemiol. 2006 Jan;59(1):7-10.

17. Fiocco M, Putter H, van Houwelingen JC. Meta-analysis of pairs of survival curves under heterogeneity: a Poisson correlated gamma-frailty approach. Stat Med. 2009 Dec 30;28(30):3782-97.

18. Putter H, Fiocco M, Stijnen T. Meta-analysis of diagnostic test accuracy studies with multiple thresholds using survival methods. Biom J. 2010 Feb;52(1):95-110.

19. Pijls BG, Valstar ER, Nouta KA, Plevier JW, Fiocco M, Middeldorp S, Nelissen RG. Early migration of tibial components is associated with late revision: a systematic review and meta-analysis of 21,000 knee arthroplasties. Acta Orthop. 2012 Dec;83(6):614-24. Epub 2012 Nov 9.

20. The R Project for Statistical Computing. 2008. http://www.r-project.org. Accessed 2014 May 7.

21. Swedish Hip Arthroplasty Register. Annual reports. http://www.shpr.se/en/Publications/DocumentsReports.aspx. Accessed 2014 May 7.

22. Rogers A, Kulkarni R, Downes EM. The ABG hydroxyapatite-coated hip prosthesis: one hundred consecutive operations with average 6-year follow-up. J Arthroplasty. 2003 Aug;18(5):619-25.

23. Eskelinen A, Remes V, Helenius I, Pulkkinen P, Nevalainen J, Paavolainen P. Uncemented total hip arthroplasty for primary osteoarthritis in young patients: a mid- to long-term follow-up study from the Finnish Arthroplasty Register. Acta Orthop. 2006 Feb;77(1):57-70.

24. Hamilton WG, Calendine CL, Beykirch SE, Hopper RH Jr, Engh CA. Acetabular fixation options: first-generation modular cup curtain calls and caveats. J Arthroplasty. 2007 Jun;22(4)(Suppl 1):75-81.

25. Philippe M, Ameil M. Survival analysis at 10 years of a cohort of 297 atlas total hip prostheses. Eur J Orthop Surg Traumatol. 2007;17:573-8.

26. Ritter MA. The cemented acetabular component of a total hip replacement. All polyethylene versus metal backing. Clin Orthop Relat Res. 1995 Feb;(311):69-75.

27. Amstutz HC, Le Duff MJ, Campbell PA, Gruen TA, Wisk LE. Clinical and radiographic results of metal-on-metal hip resurfacing with a minimum ten-year follow-up. J Bone Joint Surg Am. 2010 Nov 17;92(16):2663-71.

28. Veitch SW, Whitehouse SL, Howell JR, Hubble MJW, Gie GA, Timperley AJ. The concentric all-polyethylene Exeter acetabular component in primary total hip replacement. J Bone Joint Surg Br. 2010 Oct;92(10):1351-5.

29. Vassan UT, Sharma S, Chowdary KP, Bhamra MS. Uncemented metal-on-metal acetabular component: follow-up of 112 hips for a minimum of 5 years. Acta Orthop. 2007 Aug;78(4):470-8.

30. Keisu K, Lindgren JU. Outcome of total hip arthroplasties with cement. Results after implantation of the Harris Design-2 prosthesis, 1983-1985. J Arthroplasty. 1996 Oct;11(7):789-96.

31. Petersen MB, Poulsen IH, Thomsen J, Solgaard S. The hemispherical Harris-Galante acetabular cup, inserted without cement. The results of an eight to eleven-year follow-up of one hundred and sixty-eight hips. J Bone Joint Surg Am. 1999 Feb;81(2):219-24.

32. Metzner G, Strassl R, Neumann DRP, Hitzl W, Ramsauer T, Dorn U. [Long-term results of the cementless Hofer-Imhof threaded titanium cup] [German]. Z Orthop Unfall. 2009 Mar-Apr;147(2):166-74. Epub 2009 Apr 8.

33. Shetty AA, Slack R, Tindall A, James KD, Rand C. Results of a hydroxyapatite-coated (Furlong) total hip replacement: a 13- to 15-year follow-up. J Bone Joint Surg Br. 2005 Aug;87(8):1050-4.

34. Partio E, von Bonsdorff H, Wirta J, Avikainen V. Survival of the Lubinus hip prosthesis. An eight- to 12-year follow-up evaluation of 444 cases. Clin Orthop Relat Res. 1994 Jun;(303):140-6.

35. Bourne RB, Rorabeck CH, Patterson JJ, Guerin J. Tapered titanium cementless total hip replacements: a 10- to 13-year followup study. Clin Orthop Relat Res. 2001 Dec;(393):112-20.

36. Gwynne-Jones DP, Garneti N, Wainwright C, Matheson JA, King R. The Morscher Press Fit acetabular component: a nine- to 13-year review. J Bone Joint Surg Br. 2009 Jul;91(7):859-64.

37. Berli BJ, Schäfer D, Morscher EW. Ten-year survival of the MS-30 matt-surfaced cemented stem. J Bone Joint Surg Br. 2005 Jul;87(7):928-33.

38. Farizon F, de Lavison R, Azoulai JJ, Bousquet G. Results with a cementless alumina-coated cup with dual mobility. A twelve-year follow-up study. Int Orthop. 1998;22(4):219-24.

39. Emms NW, Stockley I, Hamer AJ, Wilkinson JM. Long-term outcome of a cementless, hemispherical, press-fit acetabular component: survivorship analysis and dose-response relationship to linear polyethylene wear. J Bone Joint Surg Br. 2010 Jun;92(6):856-61.

40. Diks M, van den Broek C, Anderson P, van Limbeek J, Spruit M The uncemented, titanium-coated RM cup: Survival and analyses of failures. Hip Int. 2005;15:71-77.

41. Levy BA, Berry DJ, Pagnano MW. Long-term survivorship of cemented all-polyethylene acetabular components in patients 75 years of age. J Arthroplasty. 2000 Jun;15(4):461-7.

42. Keisu KS, Orozco F, Sharkey PF, Hozack WJ, Rothman RH, McGuigan FX. Primary cementless total hip arthroplasty in octogenarians. Two to eleven-year follow-up. J Bone Joint Surg Am. 2001 Mar;83(3):359-63.

43. Dohle J, Becker W, Braun M. [Radiological analysis of osseointegration after implantation of the Zweymüller-Alloclassic total hip system] [German]. Z Orthop Ihre Grenzgeb. 2001 Nov-Dec;139(6):517-24.

44. Suckel A, Geiger F, Kinzl L, Wulker N, Garbrecht M. Long-term results for the uncemented Zweymuller/Alloclassic hip endoprosthesis. A 15-year minimum follow-up of 320 hip operations. J Arthroplasty. 2009 Sep;24(6):846-53. Epub 2008 Sep 11.

45. Ochs U, Eingartner C, Volkmann R, Ochs BG, Huber C, Weller S, Weise K. Prospective long-term follow-up of the cementless bicontact hip stem with plasmapore coating. Z Orthop Unfall. 2007 Sep-Oct;145(Suppl 1):S3-8.

46. Bodén H, Salemyr M, Sköldenberg O, Ahl T, Adolphson P. Total hip arthroplasty with an uncemented hydroxyapatite-coated tapered titanium stem: results at a minimum of 10 years' follow-up in 104 hips. J Orthop Sci. 2006 Mar;11(2):175-9.

47. Meding JB, Keating EM, Ritter MA, Faris PM, Berend ME. Minimum ten-year follow-up of a straight-stemmed, plasma-sprayed, titanium-alloy, uncemented femoral component in primary total hip arthroplasty. J Bone Joint Surg Am. 2004 Jan;86(1):92-7.

48. Rasquinha VJ, Ranawat CS. Durability of the cemented femoral stem in patients 60 to 80 years old. Clin Orthop Relat Res. 2004 Feb;(419):115-23.

49. Chatelet JC, Setiey L. [Long term bone behavior in total primary hip arthroplasty with a fully hydroxyapatite-coated femoral stem: a continuous series of 120 cases with twelve years follow-up] [French]. Rev Chir Orthop Reparatrice Appar Mot. 2004 Nov;90(7):628-35.

50. Young L, Duckett S, Dunn A. The use of the cemented Exeter Universal femoral stem in a District General Hospital: a minimum ten-year follow-up. J Bone Joint Surg Br. 2009 Feb;91(2):170-5.

51. Mannan K, Freeman MAR, Scott G. The Freeman femoral component with hydroxyapatite coating and retention of the neck: an update with a minimum follow-up of 17 years. J Bone Joint Surg Br. 2010 Apr;92(4):480-5.

52. Datir SP, Kurta IC, Wynn-Jones CH. Ten-year survivorship of rough-surfaced femoral stem with geometry similar to Charnley femoral stem. J Arthroplasty. 2006 Apr;21(3):392-7.

53. Jewett BA, Collis DK. Radiographic failure patterns of polished cemented stems. Clin Orthop Relat Res. 2006 Dec;453(453):132-6.

54. Grant P, Nordsletten L. Total hip arthroplasty with the Lord prosthesis. A long-term follow-up study. J Bone Joint Surg Am. 2004 Dec;86(12):2636-41.

55. Savilahti S, Myllyneva I, Pajamäki KJ, Lindholm TS. Survival of Lubinus straight (IP) and curved (SP) total hip prostheses in 543 patients after 4-13 years. Arch Orthop Trauma Surg. 1997;116(1-2):10-3.

56. Emerson RH Jr, Head WC, Emerson CB, Rosenfeldt W, Higgins LL. A comparison of cemented and cementless titanium femoral components used for primary total hip arthroplasty: a radiographic and survivorship study. J Arthroplasty. 2002 Aug;17(5):584-91.

57. Lombardi AV Jr, Berend KR, Mallory TH, Skeels MD, Adams JB. Survivorship of 2000 tapered titanium porous plasma-sprayed femoral components. Clin Orthop Relat Res. 2009 Jan;467(1):146-54. Epub 2008 Oct 31.

58. Capello WN, D'Antonio JA, Jaffe WL, Geesink RG, Manley MT, Feinberg JR. Hydroxyapatite-coated femoral components: 15-year minimum followup. Clin Orthop Relat Res. 2006 Dec;453(453):75-80.

59. Mohajer MA, Hofmann F, Graf R. Retrospective and consecutive analysis of the long-term outcomes of the SBG stem: a 15-year follow-up study. Arch Orthop Trauma Surg. 2010 Feb;130(2):185-90. Epub 2009 Jul 17.

60. Santori FS, Santori N. Mid-term results of a custom-made short proximal loading femoral component. J Bone Joint Surg Br. 2010 Sep;92(9):1231-7.

61. Parvizi J, Keisu KS, Hozack WJ, Sharkey PF, Rothman RH. Primary total hip arthroplasty with an uncemented femoral component: a long-term study of the Taperloc stem. J Arthroplasty. 2004 Feb;19(2):151-6.

62. Johnsson R, Thorngren KG, Persson BM. Revision of total hip replacement for primary osteoarthritis. J Bone Joint Surg Br. 1988 Jan;70(1):56-62.

63. Espehaug B, Furnes O, Havelin LI, Engesaeter LB, Vollset SE. The type of cement and failure of total hip replacements. J Bone Joint Surg Br. 2002 Aug;84(6):832-8.

64. Espehaug B, Furnes O, Engesaeter LB, Havelin LI. 18 years of results with cemented primary hip prostheses in the Norwegian Arthroplasty Register: concerns about some newer implants. Acta Orthop. 2009 Aug;80(4):402-12.

65. Hop JD, Callaghan JJ, Olejniczak JP, Pedersen DR, Brown TD, Johnston RC. The Frank Stinchfield Award. Contribution of cable debris generation to accelerated polyethylene wear. Clin Orthop Relat Res. 1997 Nov;(344):20-32.

66. Skutek M, Bourne RB, Rorabeck CH, Burns A, Kearns S, Krishna G. The twenty to twenty-five-year outcomes of the Harris design-2 matte-finished cemented total hip replacement. A concise follow-up of a previous report. J Bone Joint Surg Am. 2007 Apr;89(4):814-8.

67. Neumann DRP, Thaler C, Hitzl W, Huber M, Hofstädter T, Dorn U. Long-term results of a contemporary metal-on-metal total hip arthroplasty: a 10-year follow-up study. J Arthroplasty. 2010 Aug;25(5):700-8.

68. Macheras G, Kateros K, Kostakos A, Koutsostathis S, Danomaras D, Papagelopoulos PJ. Eight- to ten-year clinical and radiographic outcome of a porous tantalum monoblock acetabular component. J Arthroplasty. 2009 Aug;24(5):705-9. Epub 2008 Aug 13.

69. de Jong PT, van der Vis HM, de Man FHR, Marti RK. Weber rotation total hip replacement: a prospective 5- to 20-year followup study. Clin Orthop Relat Res. 2004 Feb;(419):107-14.

70. Delaunay C, Kapandji AI. Survival analysis of cementless grit-blasted titanium total hip arthroplasties. J Bone Joint Surg Br. 2001 Apr;83(3):408-13.

71. Zwartele R, Peters A, Brouwers J, Olsthoorn P, Brand R, Doets C. Long-term results of cementless primary total hip arthroplasty with a threaded cup and a tapered, rectangular titanium stem in rheumatoid arthritis and osteoarthritis. Int Orthop. 2008 Oct;32(5):581-7. Epub 2007 Jul 3.

72. Kobayashi S, Saito N, Horiuchi H, Iorio R, Takaoka K. Poor bone quality or hip structure as risk factors affecting survival of total-hip arthroplasty. Lancet. 2000 Apr 29;355(9214):1499-504.

73. Mäkelä K, Eskelinen A, Pulkkinen P, Paavolainen P, Remes V. Cemented total hip replacement for primary osteoarthritis in patients aged 55 years or older: results of the 12 most common cemented implants followed for 25 years in the Finnish Arthroplasty Register. J Bone Joint Surg Br. 2008 Dec;90(12):1562-9.

74. von Schewelov T, Sanzén L, Besjakov J, Carlsson A. The Elite-Plus stem migrates more than the flanged Charnley stem. Acta Orthop. 2010 Jun;81(3):280-5.

75. Hook S, Moulder E, Yates PJ, Burston BJ, Whitley E, Bannister GC. The Exeter Universal stem: a minimum ten-year review from an independent centre. J Bone Joint Surg Br. 2006 Dec;88(12):1584-90.

76. Journeaux SF, Morgan DA, Donnelly WJ. The medium-term results of a cemented Freeman femoral neck-retaining prosthesis. J Bone Joint Surg Br. 2000 Mar;82(2):188-91.

77. Skinner JA, Todo S, Taylor M, Wang JS, Pinskerova V, Scott G. Should the cement mantle around the femoral component be thick or thin? J Bone Joint Surg Br. 2003 Jan;85(1):45-51.

78. Skinner JA, Kroon PO, Todo S, Scott G. A femoral component with proximal HA coating. An analysis of survival and fixation at up to ten years. J Bone Joint Surg Br. 2003 Apr;85(3):366-70.

79. Räber DA, Czaja S, Morscher EW. Fifteen-year results of the Müller CoCrNiMo straight stem. Arch Orthop Trauma Surg. 2001;121(1-2):38-42.

80. Riede U, Lüem M, Ilchmann T, Eucker M, Ochsner PE. The M.E Müller straight stem prosthesis: 15 year follow-up. Survivorship and clinical results. Arch Orthop Trauma Surg. 2007 Sep;127(7):587-92. Epub 2007 Jun 16.

81. Baumann B, Hendrich C, Barthel T, Bockholt M, Walther M, Eulert J, Rader CP. 9- to 11-year results of cemented titanium Mueller straight stem in total hip arthroplasty. Orthopedics. 2007 Jul;30(7):551-7.

82. Kovac S, Trebse R, Milosev I, Pavlovcic V, Pisot V. Long-term survival of a cemented titanium-aluminium-vanadium alloy straight-stem femoral component. J Bone Joint Surg Br. 2006 Dec;88(12):1567-73.

83. Jaffe WL, Hawkins CA. Normalized and proportionalized cemented femoral stem survivorship at 15 years. J Arthroplasty. 1999 Sep;14(6):708-13.

84. Engesaeter LB, Lie SA, Espehaug B, Furnes O, Vollset SE, Havelin LI. Antibiotic prophylaxis in total hip arthroplasty: effects of antibiotic prophylaxis systemically and in bone cement on the revision rate of 22,170 primary hip replacements followed 0-14 years in the Norwegian Arthroplasty Register. Acta Orthop Scand. 2003 Dec;74(6):644-51.

85. Thanner J, Freij-Larsson C, Kärrholm J, Malchau H, Wesslén B. Evaluation of Boneloc. Chemical and mechanical properties, and a randomized clinical study of 30 total hip arthroplasties. Acta Orthop Scand. 1995 Jun;66(3):207-14.

86. Muirhead-Allwood SK. Lessons of a hip failure. BMJ. 1998 Feb 28; 316(7132):644.

87. Faro LM, Huiskes R. Quality assurance of joint replacement. Legal regulation and medical judgement. Acta Orthop Scand Suppl. 1992;250:1-33.

88. Cohen D. Out of joint: the story of the ASR. BMJ. 2011;342:d2905. Epub 2011 May 13.

89. Franklin J, Robertsson O, Gestsson J, Lohmander LS, Ingvarsson T. Revision and complication rates in 654 Exeter total hip replacements, with a maximum follow-up of 20 years. BMC Musculoskelet Disord. 2003 Mar 25;4:6. Epub 2003 Mar 25.

90. Sundfeldt M, Carlsson LV, Johansson CB, Thomsen P, Gretzer C. Aseptic loosening, not only a question of wear: a review of different theories. Acta Orthop. 2006 Apr;77(2):177-97.

91. Valstar ER, Nelissen RG, Reiber JH, Rozing PM. The use of roentgen stereophotogrammetry to study micromotion of orthopaedic implants. ISPRS J Photogramm Remote Sens. 2002;56:376-89.

92. Nelissen RG, Brand R, Rozing PM. Survivorship analysis in total condylar knee arthroplasty. A statistical review. J Bone Joint Surg Am. 1992 Mar;74(3):383-9.

93. Keurentjes JC, Fiocco M, Schreurs BW, Pijls BG, Nouta KA, Nelissen RG. Revision surgery is overestimated in hip replacement. Bone Joint Res. 2012 Oct;1(10):258-62. Epub 2012 Oct 1.

94. Labek G, Sekyra K, Pawelka W, Janda W, Stöckl B. Outcome and reproducibility of data concerning the Oxford unicompartmental knee arthroplasty: a structured literature review including arthroplasty registry data. Acta Orthop. 2011 Apr;82(2):131-5. Epub 2011 Mar 24.

95. Wilmshurst P. The regulation of medical devices. BMJ. 2011;342:d2822. Epub 2011 May 13.

96. Nelissen RGHH, Pijls BG, Kärrholm J, Malchau H, Nieuwenhuijse MJ, Valstar ER. RSA and registries: the quest for phased introduction of new implants. J Bone Joint Surg Am. 2011 Dec 21;93(Suppl 3):62-5.

97. Sedrakyan A. Hip resurfacing: a complex challenge for device regulation. Lancet. 2012 Nov 17;380(9855):1720-2. Epub 2012 Oct 2.

98. McCulloch P, Altman DG, Campbell WB, Flum DR, Glasziou P, Marshall JC, Nicholl J, Aronson JK, Barkun JS, Blazeby JM, Boutron IC, Campbell WB, Clavien PA, Cook JA, Ergina PL, Feldman LS, Flum DR, Maddern GJ, Nicholl J, Reeves BC, Seiler CM, Strasberg SM, Meakins JL, Ashby D, Black N, Bunker J, Burton M, Campbell M, Chalkidou K, Chalmers I, de Leval M, Deeks J, Ergina PL, Grant A, Gray M, Greenhalgh R, Jenicek M, Kehoe S, Lilford R, Littlejohns P, Loke Y, Madhock R, McPherson K, Meakins J, Rothwell P, Summerskill B, Taggart D, Tekkis P, Thompson M, Treasure T, Trohler U, Vandenbroucke J; Balliol Collaboration. No surgical innovation without evaluation: the IDEAL recommendations. Lancet. 2009 Sep 26;374(9695):1105-12.

99. McCulloch P, Barkun J, Sedrakyan A; IDEAL Collaboration. Implantable device regulation in Europe. Lancet. 2012 Aug 25;380(9843):729.