EOR | volume 6 | november 2021
DOI: 10.1302/2058-5241.6.210048
www.efortopenreviews.org

EFORT open reviews

The accuracy and reliability of preoperative digital 2D templating in prosthesis size prediction in uncemented versus cemented total hip arthroplasty: a systematic review and meta-analysis

Joshua B.V. Smith[1]
Habeeb Bishi[1]
Chao Wang[2]
Vipin Asopa[1]
Richard E. Field[1]
David H. Sochart[1]

- The purpose of this study was to compare the accuracy and the inter- and intra-observer reliability of preoperative digital 2D templating in prosthesis size prediction for the planning of cemented or uncemented THA.
- This study was registered in the NIHR PROSPERO database (ID: CRD42020216649) and conducted according to the PRISMA guidelines. A search of electronic databases in March 2021 found 29 papers overall. The quality of evidence was assessed using the IHE Quality Appraisal of Case Series Studies Checklist and the CASP Randomised Controlled Trials Checklist. A meta-analysis was conducted, and the accuracy was presented as proportions and the inter- and intra-observer reliability were measured using intraclass correlation coefficients (ICC).
- Accuracy within one prosthesis size (±1) for cemented stems was 0.89 (95% confidence interval (CI) 0.83–0.95), cemented cups 0.78 (95% CI 0.67–0.89), uncemented stems 0.74 (95% CI 0.66–0.82) and uncemented cups 0.73 (95% CI 0.67–0.79) (test of group differences: $p = 0.010$). Inter-observer reliability (ICC) for uncemented cups was 0.88 (95% CI 0.85–0.91), uncemented stems 0.86 (95% CI 0.81–0.91), cemented stems 0.69 (95% CI 0.54–0.84) and cemented cups 0.68 (95% CI 0.55–0.81) (test of group differences: $p = 0.004$). Due to lack of data, intra-observer reliability (ICC) could only be calculated for uncemented prostheses, which for the stems was 0.90 (95% CI 0.88–0.92) and for the cups was 0.87 (95% CI 0.83–0.90) (test of group differences: $p = 0.124$).
- The accuracy of preoperative digital templating is greater for cemented prostheses, but the inter-observer reliability is greater for uncemented prostheses. The intra-observer reliability showed a high level of agreement for uncemented prostheses.

Keywords: accuracy; cemented; digital templating; hip arthroplasty; reliability; uncemented

Cite this article: *EFORT Open Rev* 2021;6:1020-1039. DOI: 10.1302/2058-5241.6.210048

Introduction

The aims of total hip arthroplasty (THA) are to restore correct and personalized limb biomechanics and to achieve successful long-term fixation and function of the implant. The main benefit for preoperative templating in THA is that it allows accurate prediction of prosthesis size, shape and position and this enables the aforementioned aims of THA to be achieved.[1–7]

With a single templating software package, multiple implants from different manufactures can be templated and these are automatically updated. Preoperative templating allows the preoperative recognition of any difficulty, and it allows any intra-operative mistakes to be recognized when there are gross size discrepancies between trial and templated components.[4] It also creates an easily accessible archived record of the preoperative planning process that can be accessed by different members of the surgical team. It can then be used for postoperative evaluation, planning future surgeries on the same patient or evidence should complications or medico-legal issues arise.

Preoperative templating also formulates a plan that allows the surgical team to ensure that the theatres are adequately stocked with the relevant prosthesis sizes and suitable alternatives, should they be required. It also allows the ordering of non-standard implants and materials, such as bone graft, and helps reduce the costs associated with keeping and storing surplus inventory.[8]

One aspect that has not previously been covered in depth is the comparison of the usefulness of preoperative digital two-dimensional (2D) templating in planning both cemented and uncemented THA. It is possible that with uncemented prostheses surgeons will sometimes use a smaller prosthesis size than originally planned in order to reduce the risk of limb lengthening or peri-prosthetic fracture, which could result in over-estimation of the implant size on digital templating.[3] However, when templating for cemented prostheses the cement mantle also has to be considered, which may be more subjective and less reliable than the clear bony landmarks used to guide templating for uncemented prostheses.[5] There has, therefore, been some dispute regarding whether preoperative digital templating is of greater accuracy for cemented or uncemented prostheses.

This is the first systematic review and meta-analysis comparing the accuracy and reliability of preoperative digital 2D templating for both cemented and uncemented THA. The aims of this review are to assess the differences in the preoperative digital 2D templating accuracy and inter- and intra-observer reliability between cemented and uncemented THA prostheses.

Methods

This systematic review and meta-analysis was registered in the NIHR (National Institute for Health Research) PROSPERO (International Prospective Register of Systematic Reviews) database (ID: CRD42020216649) and the protocol can be viewed at https://www.crd.york.ac.uk/prospero/.[6] The review process was conducted according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[9]

Search strategy

A systematic literature search was performed using the following electronic databases: Ovid Medline; Ovid Embase; PubMed; HDAS Embase; HDAS Medline; Cochrane library. The following grey literature sources and trial registries were searched: MEDRXIV; OpenGrey; ClinicalTrials.gov; Cochrane CENTRAL Database; WHO International Clinical Trials Registry Platform (ICTRP); EU Clinical Trials Registry. The dates of coverage were all papers up to and including 8 March 2021 and the search strategy used in PubMed can be seen in Table 1. No limits were applied and the reference lists of the selected papers were also searched for other relevant papers.

Table 1. Search strategy used in PubMed literature search

Search line	Search terms
1	"BONE CEMENTS" [MeSH Terms]
2	Uncement* OR cement*
3	1 OR 2
4	Templat*
5	"ARTHROPLASTY, REPLACEMENT, HIP"[MeSH Terms] OR "HIP PROSTHESIS" [MeSH Terms]
6	"Hip prosthesis" OR THA OR THR OR "Total hip replacement" OR "Total hip arthroplasty" OR "Hip replacement"
7	5 OR 6
8	3 AND 4 AND 7

Study selection

The following inclusion and exclusion criteria were applied in order to determine the studies to be used:

Inclusion criteria

- THA patients (any indication for surgery)
- Uncemented and/or cemented prostheses (acetabular cups and/or femoral stems)
- Digital templating used as the method of templating
- Official digital templating software used
- Papers reporting the accuracy and/or inter-observer reliability and/or intra-observer reliability of preoperative digital templating in THA
- Papers from any date of publication
- Papers in English/translated into English
- Papers published electronically and/or in print

Exclusion criteria:

- Full texts not in English (or not translated into English)
- Papers with a mixed cohort of both cemented and uncemented THA prostheses without a direct comparison between the two

Only studies with specific and individual data (accuracy, inter-observer reliability or intra-observer reliability) for uncemented and/or cemented prostheses were used in order to allow a direct comparison between the two designs. For restricted access papers local trust librarians were contacted in order to gain access.

The study selection process, screening for eligibility and inclusion, was independently performed by two reviewers (first and second authors). Any papers that did not meet the inclusion criteria were excluded and all papers that satisfied the inclusion criteria were included. A third reviewer (senior author) was available to resolve any potential disputes in the study selection process.

Quality of evidence and risk of bias assessment

The quality of evidence and risk of bias were assessed at the study level according to the Institute of Health Economics (IHE) Quality Appraisal of Case Series Studies Checklist[10] or the Critical Appraisals Skills Programme (CASP) Randomised Controlled Trials Checklist,[11] depending upon the study type. The IHE checklist was modified, as per the official recommendations, by removing any criteria irrelevant for this study (e.g. co-interventions and follow-up). The critical appraisal was independently performed by two of the authors (first and second authors) and a third reviewer (senior author) was available to resolve any potential disputes.

Data extraction

Data from the eligible papers were incorporated into a standardized data abstraction form in Microsoft Excel for analysis. Studies were grouped based upon the type of THA prosthesis used (i.e. cemented or uncemented femoral stem and cemented or uncemented acetabular cup) and the type of preoperative digital templating analysis (i.e. accuracy, inter-observer reliability or intra-observer reliability).

Additional data were extracted from each paper in order to allow for subgroup analyses in the meta-analysis. This data included the level of experience of the individual performing the templating, the indication for surgery, the method of correcting for X-ray magnification and the presence of an X-ray magnification reference object. In order to assess this data some simplifications were made. For the level of templating experience of the templating practitioner, surgeons were classed as 'senior', and residents or equivalent roles (i.e. all non-surgeons), were grouped together as 'junior'. A further 'mixed' group included both senior and junior templating practitioners.

The indications for surgery were grouped as either 'complex', which included hips with deformities and technical issues such as dysplastic hips (developmental dysplasia of the hip – DDH), femoral head necrosis (avascular necrosis – AVN) and Perthes' disease, or 'simple', which included osteoarthritis (OA) and rheumatoid arthritis (RA). An extra group entitled 'mixed' was used to represent both 'complex' and 'simple' indications for surgery that were not analysed separately. The method of preoperative X-ray magnification for templating was categorized as either being automatically completed by the 'templating software' or by a 'manual method'. The specific 'manual method' details are described for the respective studies in Table 2.

Outcomes

The outcomes assessed were accuracy, inter-observer reliability and intra-observer reliability of preoperative digital templating for both cemented and uncemented implants (acetabular cups and femoral stems).

The accuracy (measured as proportions) was calculated by comparing the number of implanted prostheses that were exactly the same size as the templated size, within (±1) one size difference or within (±2) two size differences. Throughout the literature a difference of (±1) one size was widely regarded as acceptable.[5] The inter-observer reliability was the measure of agreement between the templating results of multiple observers. The intra-observer reliability was the measure of agreement between the templating results of the same observer taken over multiple time points. The values used to determine the level of agreement in both the inter-observer and intra-observer reliabilities were weighted kappa values (κ), intra-class correlation coefficients (ICC) and the Pearson correlation coefficient (PCC).

Statistical analysis

A series of random-effects meta-analyses was performed for accuracy (repeated for exact, one-size and two-size differences) and reliability measures (repeated for inter-observer and intra-observer reliabilities). For reliability measures, the standard error for each ICC was calculated using the 95% CI when reported, but, if not, the standard error was calculated using the formula detailed by Borenstein et al.[12] There were not many studies that reported the PCC and standard errors or 95% CIs for kappa values, so PCC and kappa values were not included in the meta-analyses. DerSimonian-Laird (DL) or profile likelihood (PL) methods were used in the random-effects models as suggested by Kontopantelis and Reeves.[13] Heterogeneity was measured using the I^2 statistic. Subgroup analyses by type of prosthesis or other factors were performed for each meta-analysis to account for heterogeneity and assess between-group differences. Those that failed to reach statistical significance in the test of group differences were not detailed in the results section. The meta-analyses were performed using the 'metan' package (version 4.02) in Stata 16.1[14] and the results were presented as forest plots.

Results

Search results and characteristics

The number of papers screened, assessed for eligibility and included in the review are detailed in the PRISMA flowchart (Fig. 1), with the study characteristics shown in Table 2.

The systematic review and meta-analysis included a total of 29 papers. Twenty-four studies investigating accuracy, five investigating inter-observer reliability and five investigating intra-observer reliability were included in the meta-analysis. The papers used have been detailed

Table 2. Details of the 29 studies that were included from the literature search

Author + year of publication	Type of study	No. of THAs (or no. of cups + stems)	Person performing the templating	X-ray magnification reference object (+ location)	Templating software	X-ray magnification correction technique	Prosthesis design	Demographics (age, gender, BMI)	Indications for THA	QoE assessment
The et al 2005[16]	R-CS	CEM = 112 UCM = 61	First author	Yes (GT)	Hyper-ORTHO (Rogan-Delft BV)	TS	**UCM stem**: Mallory Head (MH) prosthesis **UCM cup**: metal backed cup **CEM stem**: Scientific Hip Prosthesis (SHP) **CEM cup**: all poly (Biomet)	NS	OA	IHE 12/16
The et al 2007[5]	RCT	CEM = 73 UCM = 31	Operating surgeon. Intra- and inter-observer reliability = 8 different surgeons (34 THAs)	Yes (GT)	Hyper-ORTHO (Rogan-Delft BV)	TS	**UCM stem and cup**: Mallory/head prosthesis with metal-backed cup **CEM stem and cup**: Scientific Hip Prosthesis all-poly cup (Biomet)	Mean age 65 years (*SD* 14.9) Female 64% Mean BMI 27.7 kg/m² (*SD* 4.7)	OA RA (15%) AVN (36%)	CASP 10/11
Wedemeyer et al 2008[17]	P-CS	UCM = 40	Average of two surgeons	Yes (GT)	MediCad-system Version 2.06 (Hectec)	TS	**UCM cup:** Duraloc (DePuy) or Trident PSL (Stryker) **UCM stem:** Mayo short stem (Zimmer)	Average age 45.8 years (±9.5) Female 47.5%	AVN (65%) OA (35%)	IHE 14/16
González Della Valle et al 2008[18]	P-CS	Hybrid = 64	One of authors	Yes (GT)	Impax ver 5.0 software package (Agfa Corporation)	TS	**UCM cup**: Trilogy cup **CEM stem**: VerSys Heritage (Both Zimmer)	Left hip in 32 cases. Demographics NS	Primary OA	IHE 10/16
Kosashvili et al 2009[19]	P-CS	UCM = 18	Two surgeons	No	eFilm Medical (Merge Healthcare)	TS	**UCM cup and stem**: Trilogy acetabular cup + VerSys Fibre Metal Taper femoral stem (both Zimmer)	NS	Primary OA	IHE 10/16
Crooijmans et al 2009[20]	R-CS	CEM = 17 UCM = 16	2 orthopaedic surgeons + 2 orthopaedic residents (one of each templated the uncemented THAs a second time)	Yes (PS)	IMPAX ES Orthopaedic Application planning software (Agfa Healthcare)	TS + manual method (corrected magnification factor determined in study taking into account magnification of the hip)	**CEM stem**: Muller Straight Stem **CEM cup**: Muller Low Profile **UCM stem**: CLS Spotorno **UCM cup**: Fitmore Shell with Fitec poly insert (All Zimmer)	Between 50 and 83 years of age. **UCM** Female 62.5% **CEM** Female 82.4%	NS	IHE 10/16
Kumar et al 2009[21]	P-CS	UCM = 45	Two surgeons (one repeated)	Yes (GT)	TraumaCad (Voyant Health)	TS	**UCM stem**: uncollared Corail **UCM cup**: Pinnacle (Both DePuy)	NS	NS	IHE 13/16
Gamble et al 2010[22]	R-CS	UCM = 40	2 senior staff surgeons and 1 senior resident	Yes ('placed in groin')	Orthoview (Meridian Technique Ltd)	TS	**UCM cup**: Trident **UCM Stem:** Accolade or Omnifit (All Stryker)	18 males (45%) and 22 females (55%); mean age of 68 years (*SD* 11.9)	OA	IHE 12/16
Whiddon et al 2011[23]	R-CS	UCM = 51	Arthroplasty fellows	Yes ('at bone level')	Impax (Agfa)	TS	**UCM cup and stem**: Trident acetabular cup. Secur-Fit Max or Accolade femoral stems (all Stryker)	Mean age 59.9 years (*SD* 11.5). Mean BMI 27.7 kg/m² (*SD* 5.8)	NS	IHE 12/16
Zhao et al 2011[24]	Retrospective Case-control study	UCM = 41 for Crowe type 2/3 dysplastic hips UCM = 48 for other diseases	Two investigators (level of experience NS)	No	Cedara I-Reach (Merge Healthcare)	Manual method (average magnification factor determined in the study)	**UCM cup and stem**: Secur-Fit HA stem and Osteonics Crossfire / Osteonics ceramic acetabular cups (both Stryker)	Dysplastic hips: 20 females (57.1%) and 15 males (42.9%) aged between 49–65 years. Other diseases: 20 females (45.5%) and 24 males (54.5%) aged between 55–79 years	23 Crowe type II hips and 18 Crowe type III hips. Other diseases: fractured femoral neck (*n* = 14), femoral head necrosis (*n* = 13) and primary OA (*n* = 21)	IHE 10/6

(continued)

Table 2. (continued)

Author + year of publication	Type of study	No. of THAs (or no. of cups + stems)	Person performing the templating	X-ray magnification reference object (+ location)	Templating software	X-ray magnification correction technique	Prosthesis design	Demographics (age, gender, BMI)	Indications for THA	QoE assessment
Fottner et al 2011[25]	R-CS	CEM stem = 71 UCM stem = 49	Orthopaedic surgeon	Yes (GT)	EndoMap VA20A (Siemens)	TS	**Cem stem**: MS30 Zimmer **UCM stem**: CR-stem Implantacast **UCM cup**: screw-cups SC Aesculap	46 men, 61 women, average age 70.7 years (range 42–88 years)	101 OA, 14 aseptic necroses of the femoral head, 5 OA due to dysplasia	IHE 11/16
Gallart et al 2012[26]	R-CS	UCM = 55	Surgeon	Yes (pubic symphysis)	Neteous (Socinser)	TS	**UCM cup and stem**: PROSIC cup + stem (Socinser)	22 women (40%) and 33 men (60%). Mean age 63 (range 26–84)	OA (main diagnosis)	IHE 12/16
Issa et al 2012[27]	P-CS	UCM = 100 first-generation stems UCM = 100 second-generation stems	Experience NS. 25 X-rays in each group randomly re-assessed	Yes (NS)	TraumaCad (Voyant Health)	TS	**UCM cup and stem**: 1st generation: Accolade TMZF (Stryker). Second generation: Accolade II (Stryker)	First-generation stem: 46 males (46%) and 54 females (54%); mean age 56 years (range 23–80). Second-generation stem: 52 males (52%) and 48 females (48%); mean age 55 (range 19–79)	NS	IHE 13/16
Schmidutz et al 2012[28]	R-CS	UCM = 50 for SHAs UCM = 50 for conventional THAs	Attending physician, fifth-year resident, third-year resident and first-year resident	Yes (GT)	EndoMap (Siemens)	TS	**UCM cup and stem**: SHA: Metha, Aesculap uncemented. Conventional THA: CR-Stem Implantacast. Acetabular component: Screwcup or Plasmacup, Aesculap	SHA: 30 males (60%) and 20 females (40%); mean age 55.1 years (±11.6 years) (range 24–71 years). Conventional THA: 26 males (52%) and 24 females (48%); mean age 65.0 years (±6.0 years) (age range 24–71)	SHA: OA (80%), AVN (16%) and acetabular dysplasia (4%). Conventional THA: OA (88%), AVN (4%) and acetabular dysplasia (8%)	IHE 13/16
Bertz et al 2012[29]	R-CS	Total = 129 CEM stem = 78 UCM stem = 51	Two surgeons	Yes ('inner aspect of the thigh nearest possible to the pelvis')	Mdesk (RSA Biomedical)	TS	**CEM stem**: Lubinus SPII Hip System (LINK) **CEM cup**: Elite Plus Ogee (DePuy) cup **UCM stem**: reverse hybrid Corail femoral cementless stem	85 females (65.9%) and 44 males (34.1%). Mean age 66 years	NS	IHE 14/16
Jassim et al 2012[2]	R-CS	Hybrid = 42 CEM = 17	NS	No	OrthoView (Southampton)	Manual method (magnification determined according to X-ray focal spot measurements)	**CEM stem**: Exeter stem (Stryker) **CEM cup**: Contemporary cup (Stryker) **UCM cup**: Trident cup (Stryker) or Reflection cup (Smith&Nephew)	NS	NS	IHE 11/16
Mittag et al 2012[30]	R-CS	UCM cup = 84 CEM cup = 22 CEM stem= 90 UCM stem = 16	Three orthopaedic residents + experienced orthopaedic surgeon	Yes (GT)	EndoMap (Siemens)	TS	**UCM cup**: Allofit **UCM stem:** M/L Taper **CEM cup**: Durasul **CEM stem**: Muller straight stem (All Zimmer)	54 females (50.9%) and 52 males (49.1%)	Primary OA	IHE 10/16
Shaarani et al 2013[3]	P-CS	UCM = 100	Senior author (surgeon)	Yes (NS)	Orthoview (version 2.0CEN; Meridian Technique Ltd)	TS	**UCM cup and stem**: Trident cup + Accolade stem (Stryker-Howmedica-Osteonics)	48 male (52.2%) and 44 female (47.8%). Mean age 60 years	OA	IHE 13/16

(continued)

Table 2. (continued)

Author + year of publication	Type of study	No. of THAs (or no. of cups + stems)	Person performing the templating	X-ray magnification reference object (+ location)	Templating software	X-ray magnification correction technique	Prosthesis design	Demographics (age, gender, BMI)	Indications for THA	QoE assessment
Riddick et al 2014[31]	R-CS	UCM = 53	NS	Yes (GT)	MediCad (Hectec)	Manual method (manual calculation using calibration ball)	**UCM cup and stem**: Profemur-Z stem and Procotyl cup (Wright Medical)	20 males and 33 women. Age range 17 to 80. Mean age 60 years. Mean BMI 28.6 kg/m² (range 18–45 kg/m²)	NS	IHE 8/16
Kniesel et al 2014[32]	P-CS	UCM cup = 52 (no reference ball) UCM stem = 38 (reference ball)	One surgeon	Yes ('between the legs, as near to the joint as possible')	MediCad (Hectec)	TS	**UCM cup and stem**: Bicontact stems and plasma pore-coated acetabular cups from the Aesculap company (B-Braun Melsungen AG; Tuttlingen, Germany)	Mean BMI 26.37 kg/m² (±0.7775)	NS	IHE 12/16
Hafez et al 2016[33]	P-CS	CEM = 3 UCM = 20 Hybrid = 2	NS	Yes (ASIS)	MergeOrtho (Chicago)	TS	Unknown	NS	All complex THA cases (no definition)	IHE 10/16
Shemesh et al 2017[34]	R-CS	UCM = 148	Surgeon	Yes (GT)	Orthoview (Meridian Technique Ltd)	TS	**UCM cup and stem**: Tritanium cup and Accolade II stem (Stryker)	Direct approach: mean age 62.4 years (*SD* 13.1); 44 females (59%) and 31 males (41%); mean BMI 26.6 kg/m² (*SD* 3.3). Posterior approach: mean age 60.9 years (*SD* 15.8); 45 females (62%) and 28 males (38%); mean BMI 29.8 kg/m² (SD 5.8)	Severe, end-stage OA or end-stage AVN of the femoral head	IHE 12/16
Strøm et al 2017[35]	R-CS	UCM = 34	Sixth-year resident, senior chief attending surgeon and chief attending surgeon	Yes ('between the legs, as close to the focal point of the X-ray beam as possibl')	EndoMap (Siemens)	TS	**UCM cup and stem**: Zimmer Trilogy cup and DePuy Corail stem	22 females (65%) and 12 males (35%). Age range 13 to 82 years. Mean age 51 years	Primary OA (44%), AVN of femoral head (18%), DDH (18%), Perthes' disease (12%) and miscellaneous (9%)	IHE 11/16
Dong et al 2017[36]	R-CS	UCM = 577	Senior surgeon. 31 stems + 17 cups required templating adjustment (new method used adjusting for femoral external rotation, osteoporosis in femur, osteosclerosis in acetabulum and stem type	Yes (GT)	TraumaCad (Voyant Health)	TS	**UCM cup and stem**: Trident PSL HA cup + Accolade HFx stem (Stryker) (30 patients). Duraloc cup + uncollared Corail stem (Depuy) (28 patients)	42 males (72.4%) and 16 females (33.3%). Mean age 51.05 years (±13.7 years). Range 23–74 years	Osteonecrosis of the femoral head	IHE 13/16
Strøm and Reikerås 2018[37]	R-CS	UCM = 41	Surgeons	Yes ('between the legs, as close to the focal point of the X-ray beam as possible')	EndoMap (Siemens)	TS	**UCM cup and stem**: Zimmer trilogy cup and DePuy Corail stem	26 females (63%) and 15 men (37%). Age range 13–82 years. Mean age 50 years	Primary OA (41%), DDH (22%), AVN of the femoral head (15%), Perthes' disease (10%) and miscellaneous (12%)	IHE 10/16
Holzer et al 2019[38]	R-CS	UCM = 632	Consultants or residents	Yes (GT)	Syngo-EndoMap (Siemens)	TS	**UCM cup and stem**: Allofit cup and Alloclassic stem (Zimmer). Pinnacle cup and Corail stem (DePuy)	282 male (45%) and 350 female (55%). Mean age 65.7 years (±12.1 *SD*). BMI underweight 0.5%, normal weight 28.6%, overweight 44.1% and obese 26.7%	Primary OA	IHE 12/16

(continued)

Table 2. (continued)

Author + year of publication	Type of study	No. of THAs (or no. of cups + stems)	Person performing the templating	X-ray magnification reference object (+ location)	Templating software	X-ray magnification correction technique	Prosthesis design	Demographics (age, gender, BMI)	Indications for THA	QoE assessment
Montiel et al 2020[39]	P-CS	UCM = 39	One junior resident, one senior resident and three experienced hip surgeons	Yes ('inner area of the thigh, as close as possible to the femoral head')	MediCad (Hectec)	TS	**UCM cup and stem**: Allofit cup (Zimmer) and CLS Spottorno Stem (Zimmer)	24 (61.5%) men, 15 (38.5%) women. Mean age 65 (*SD* 9). Left THA *n* = 14, (35.9%). Right THA *n* = 25 (64.1%)	NS	IHE 14/16
Shichman et al 2020[40]	P-CS	UCM = 101	Two residents and two fellowship-trained surgeons	Yes (King Mark method – radiolucent marker pad placed behind the pelvis as well as a marker with radio-opaque balls placed in front of the pelvis)	TraumaCad (Voyant Health)	TS	**UCM cup and stem**: Pinnacle cup (Depuy) and Corail stem (Depuy)	57 females, 44 males. Mean age at surgery 65.5 (*SD* 13.6). Left THA *n* = 47. Right THA *n* = 54	OA 79 patients (78.2%), DDH 13 patients (12.9%) and AVN 9 patients (8.9%). DDH and AVN operations were classed as 'complex cases'	IHE 13/16
Brenneis et al 2021[41]	Randomised CS	UCM = 28	Templated twice by two independent observers (unknown level of experience)	Yes (GT)	TraumaCad version 2.3.4.1 (Voyant Health)	TS	**UCM cup**: press-fit Allofit cup (Zimmer) **UCM stems**: diaphyseal press-fit Alloclassic Zweymuller 'Step Less' or 'Step Less Offset' straight stem (Zimmer) and metaphyseal-anchoring standard or lateralized short-stem Optimys (MathysLtd)	2D group: 12 females, 16 males. Average age 63.5 years (*SD* 10.0). 13 short stems. 15 straight stems	Unilateral OA (Kellgren Lawrence Grade ⩾ 3)	CASP 10/11

Note. CS, case series (R, retrospective; P, prospective); CEM, cemented; UCM, uncemented; GT, greater trochanter; BMI, body mass index; IHE, Institute of Health Economics; QoE, quality of evidence; CASP, Critical Appraisal Skills Programme; TS, templating software; NS, not specified; OA, osteoarthritis; RCT, randomized control trial; RA, rheumatoid arthritis; AVN, avascular necrosis; PS, pubic symphysis; SHA, short stem hip arthroplasty; ASIS, anterior superior iliac spine; DDH, developmental dysplasia of the hip; THA, total hip arthroplasty.

in Table 2 and Table 3. Any papers that were not used in the meta-analysis were still appraised as part of the systematic review.

Meta-analysis results for the accuracy of templating

There were a total of 6,305 THA prostheses (stems and cups, cemented and uncemented) included in the accuracy meta-analysis. This included 392 cemented cups, 671 cemented stems, 2,571 uncemented cups and 2,671 uncemented stems.

There was no statistically significant difference between the cemented and uncemented groups for exact accuracy (p = 0.890; Fig. 2), but when assessing accuracy for one size difference (±1) the cemented implants were more accurate than the uncemented (p = 0.002; Fig. 3). The same applied to the two-size difference analysis (±2), although only one study reported on cemented stems (p = 0.005; Fig. 4).

For all the accuracy scenarios there was a high heterogeneity, even after accounting for the type of prosthesis, and when other factors were tested the heterogeneity remained high. Forest plots for statistically significant group factors can be seen in Figs. 5–7. These included X-ray magnification technique and indication for surgery.

Inter-observer and intra-observer reliability meta-analysis results

There were a total of 2,470 THA prostheses (stems and cups, cemented and uncemented) included in the inter-observer reliability meta-analysis. This included 89 cemented cups, 89 cemented stems, 1,121 uncemented cups and 1,171 uncemented stems.

There were a total of 1,174 THA prostheses (stems and cups, cemented and uncemented) included in the intra-observer reliability meta-analysis. This included 21 cemented cups, 21 cemented stems, 541 uncemented cups and 591 uncemented stems.

The inter-observer agreement was higher for uncemented prostheses than cemented ones (p = 0.004); Fig. 8). Suitable intra-observer reliability studies were only available for uncemented prostheses and demonstrated no significant differences between uncemented cups and

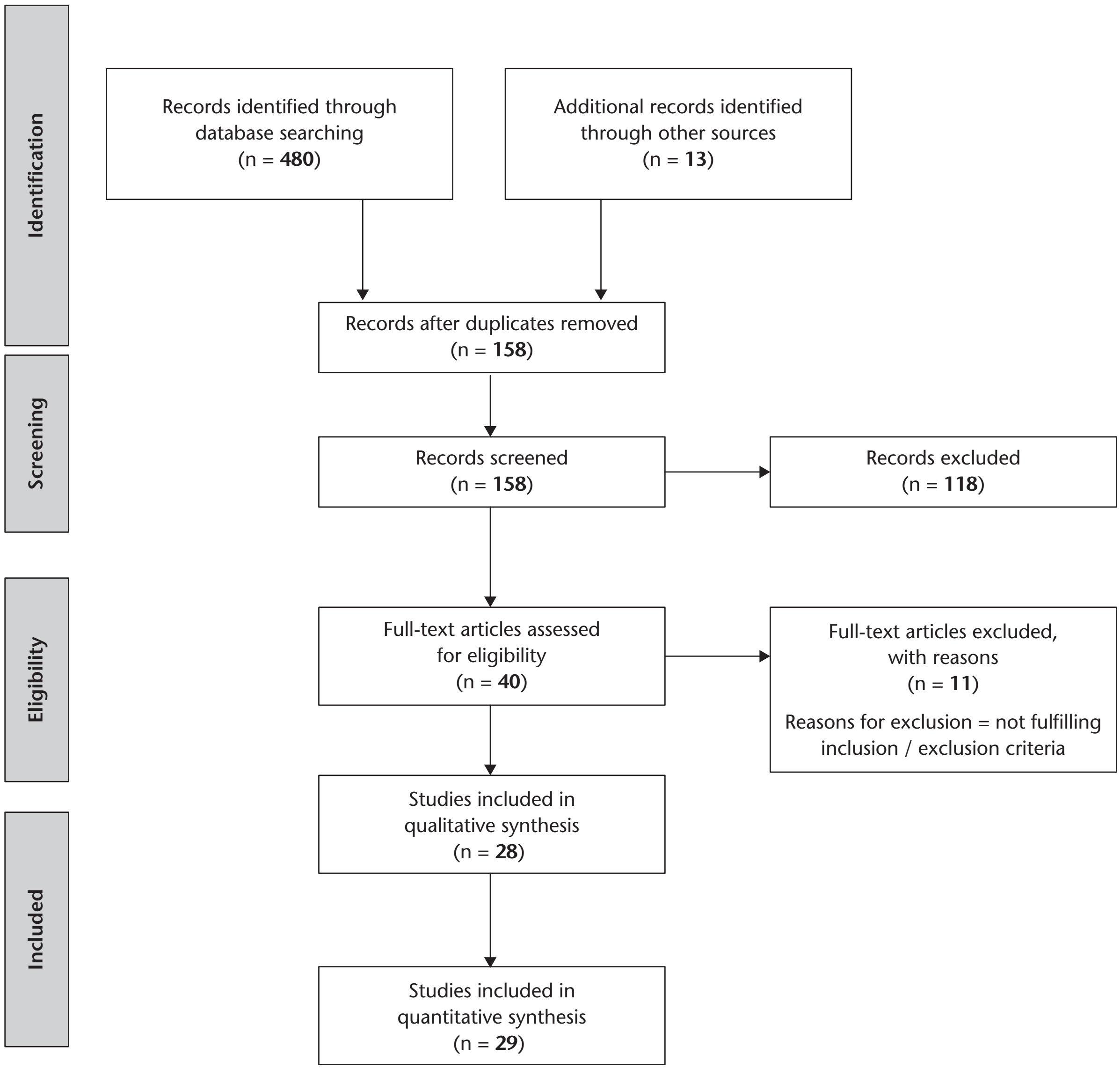


Fig. 1 PRISMA flowchart.[15]

stems (p = 0.124; Fig. 9). Inter-observer reliability, irrespective of prosthesis type (0.85 [0.82–0.88]; Fig. 8) was lower than the intra-observer reliability, irrespective of implant design (0.89 [0.87–0.91]; Fig. 9).

The heterogeneity of the inter-observer and intra-observer reliability studies is much smaller than that of the accuracy studies. Inter-observer reliability subgroup analysis of the presence of the X-ray reference object reached statistical significance (p = 0.010; Fig. 10).

Discussion

The results demonstrated that preoperative digital 2D templating had a higher level of accuracy for prosthesis size prediction in cemented prostheses than uncemented ones, but that the inter-observer reliability was higher for uncemented prostheses than cemented ones. Intra-observer reliability could only be assessed for uncemented implants and confirmed a high level of agreement for uncemented cups and stems.

The superior accuracy of templating for cemented implants may be the result of the cement mantle allowing for slight differences rather than the hard anatomical constraints of the bone required for press-fit of the uncemented ones. Incremental size increases for cemented prostheses also tend to be greater, and therefore there are fewer cemented implant sizes to select from. This consequently raises the likelihood of a closer match between the templated and implanted cemented prostheses sizes, and hence a higher level of templating accuracy.

Uncemented prostheses require under-reaming and an exact press-fit operative technique. It is more likely

Table 3. Details of the studies included in the meta-analysis for the accuracy and inter-observer and intra-observer reliability outcomes

Author + year of publication	Prosthesis design	Included in accuracy meta-analysis	Included in inter-observer reliability meta-analysis	Included in intra-observer reliability meta-analysis
The et al 2005[16]	UCM stem + cup CEM stem + cup	✓		
The et al 2007[5]	UCM stem + cup CEM stem + cup	✓		
Wedemeyer et al 2008[17]	UCM cup + stem	✓		
González Della Valle et al 2008[18]	UCM cup + stem	✓		
Kosashvili et al 2009[19]	UCM cup + stem			
Crooijmans et al 2009[20]	CEM stem + cup UCM stem + cup	✓	✓	✓
Kumar et al 2009[21]	UCM stem + cup	✓		
Gamble et al 2010[22]	UCM cup + stem	✓	✓	✓
Whiddon et al 2011[23]	UCM cup + stem	✓		
Zhao et al 2011[24]	UCM cup + stem	✓	✓	✓
Fottner et al 2011[25]	CEM stem UCM stem + cup	✓		
Gallart et al 2012[26]	UCM cup + stem			
Issa et al 2012[27]	UCM cup + stem	✓		
Schmidutz et al 2012[28]	UCM cup + stem	✓		
Bertz et al 2012[29]	CEM stem + cup UCM stem	✓		
Jassim et al 2012[2]	CEM stem + cup UCM cup	✓		
Mittag et al 2012[30]	UCM cup + stem CEM cup + stem	✓		
Shaarani et al 2013[3]	UCM cup + stem	✓		
Riddick et al 2014[31]	UCM cup + stem	✓		
Kniesel et al 2014[32]	UCM cup + stem	✓		
Hafez et al 2016[33]	Unknown			
Shemesh et al 2017[34]	UCM cup + stem	✓		
Strøm et al 2017[35]	UCM cup + stem			
Dong et al 2017[36]	UCM cup + stem	✓		
Strøm and Reikerås 2018[37]	UCM cup + stem	✓	✓	✓
Holzer et al 2019[38]	UCM cup + stem	✓		
Montiel et al 2020[39]	UCM cup + stem			
Shichman et al 2020[40]	UCM cup + stem	✓		
Brenneis et al 2021[41]	UCM cup + stems	✓	✓	✓

Note. CEM, cemented; UCM, uncemented.

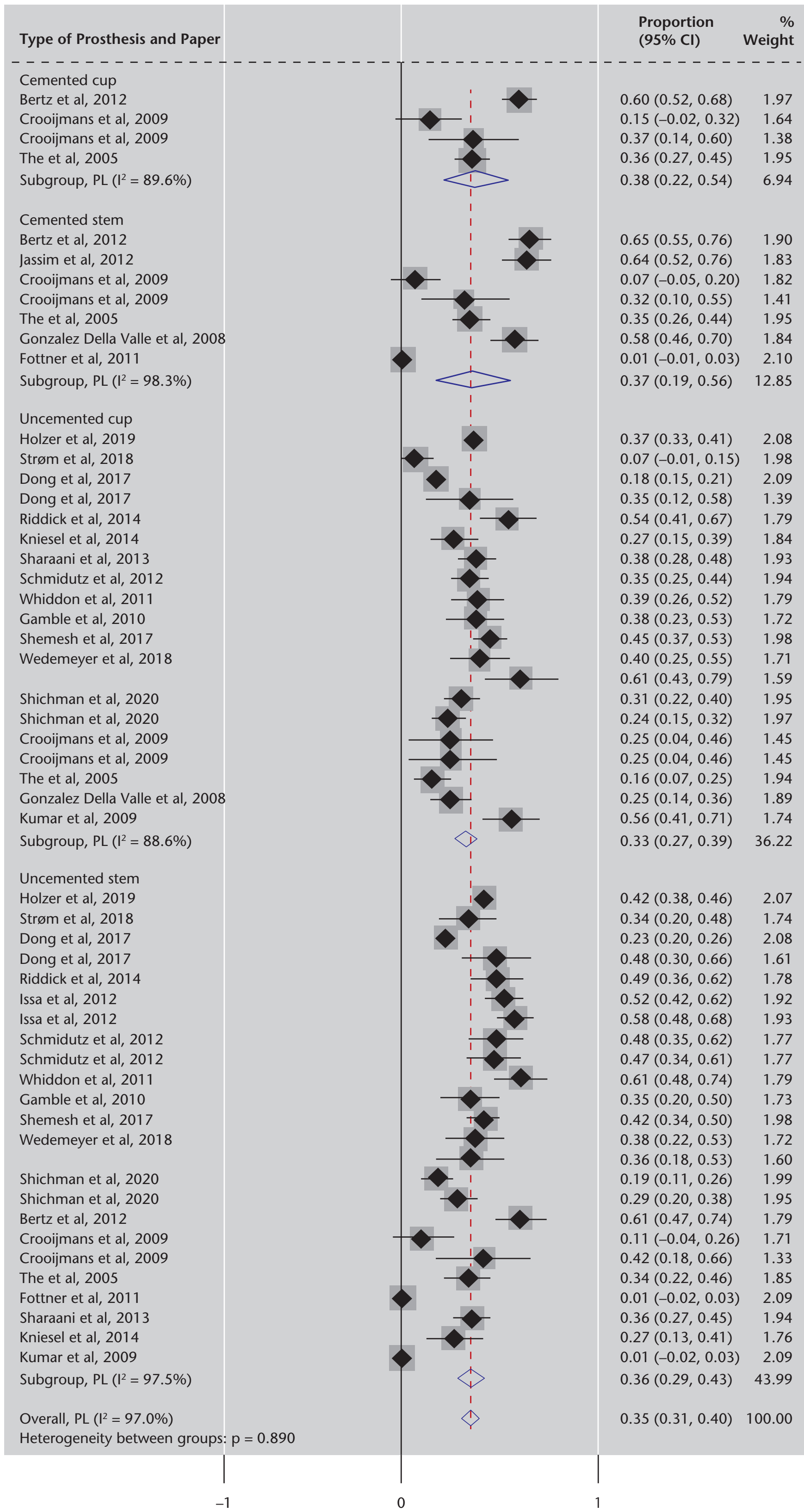
that surgeons may opt to use a smaller size of prosthesis than originally templated in order to reduce the risk of peri-prosthetic fracture or leg lengthening associated with over-sized prostheses.[19] This could theoretically contribute to the perceived lower accuracy of preoperative templating in uncemented prostheses. The insertion of uncemented prostheses is also reliant on the underlying bone quality, which is often difficult to assess on preoperative radiographs. Once again this could explain the higher accuracy when templating for cemented implants.

Interestingly, inter-observer reliability was greater for uncemented implants, which once again could be the result of the more subjective allowance of space for the cement mantle that is less reliable than using the clearer bony landmarks for guidance when templating uncemented prostheses.[30]

There were no suitable studies for the assessment of intra-observer reliability when templating cemented implants because none reported ICC values. In terms of a qualitative assessment, The et al directly compared the inter-observer and intra-observer reliabilities for both cemented and uncemented prostheses and found that the templating of uncemented THA prostheses had higher kappa values than their cemented counterparts.[5] They also found that the intra-observer reliability was always higher than the inter-observer reliability, which lends itself to the recommendation that the preoperative templating for THA should be done by the operating surgeon.

The main limitation in this meta-analysis is the heterogeneity of methodologies used in each study (Table 2). The differing types, sizes and designs of prostheses, patient numbers, indications for surgery, level of templating experience of the templating practitioner and templating software used in each study contributed to this heterogeneity. Subgroup analysis of the variables of X-ray magnification technique and indications for surgery (Figs 5–7) reached statistical significance ($p = 0.023$, $p = 0.033$ and $p = 0.008$, respectively).

Concerning X-ray magnification, the majority of the studies used the inbuilt X-ray magnification feature in the templating software, but four studies used manual X-ray magnification techniques. Some studies even included



NOTE: Weights and between-subgroup heterogeneity test are from random-effects model

Fig. 2 Forest plot for exact size accuracy meta-analysis results.

Note. CI, confidence interval; PL, profile likelihood.

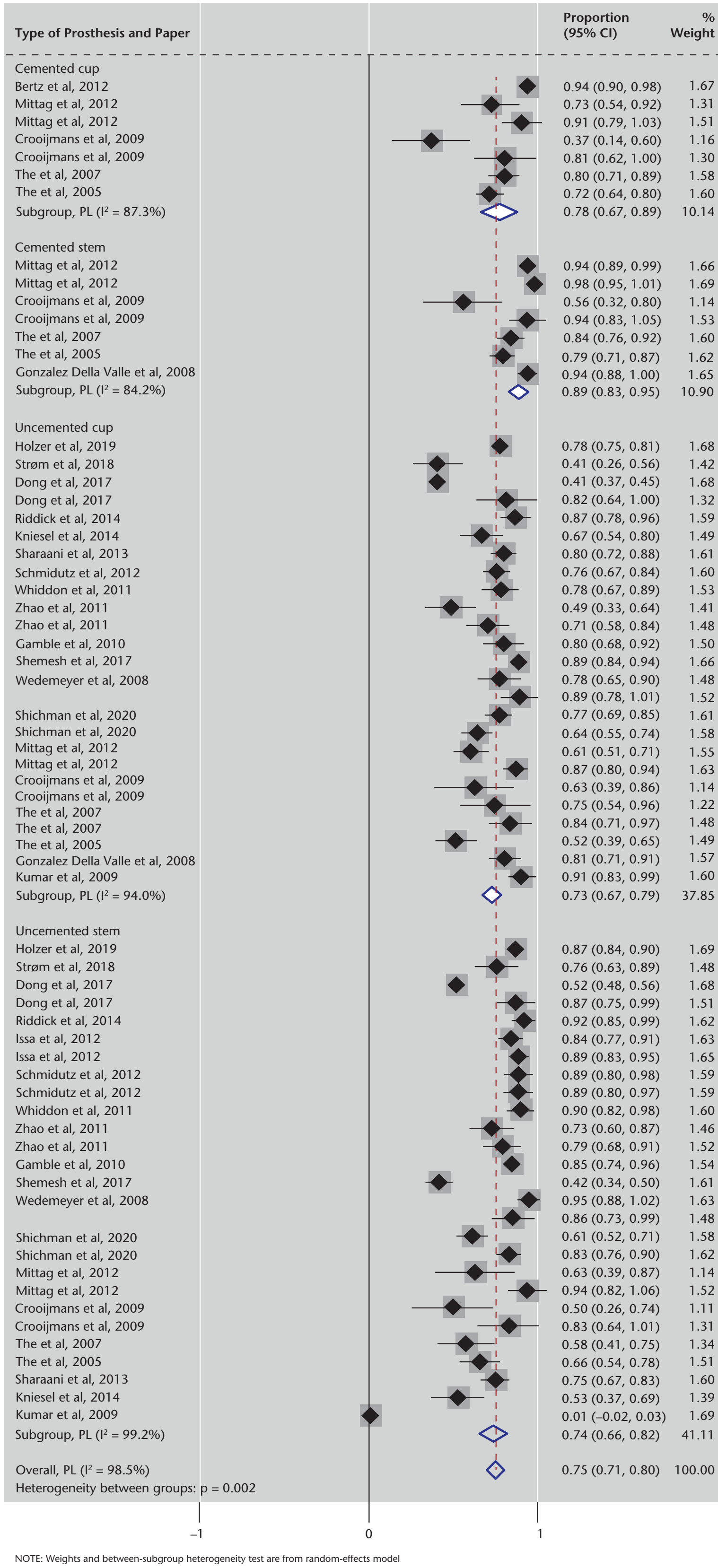
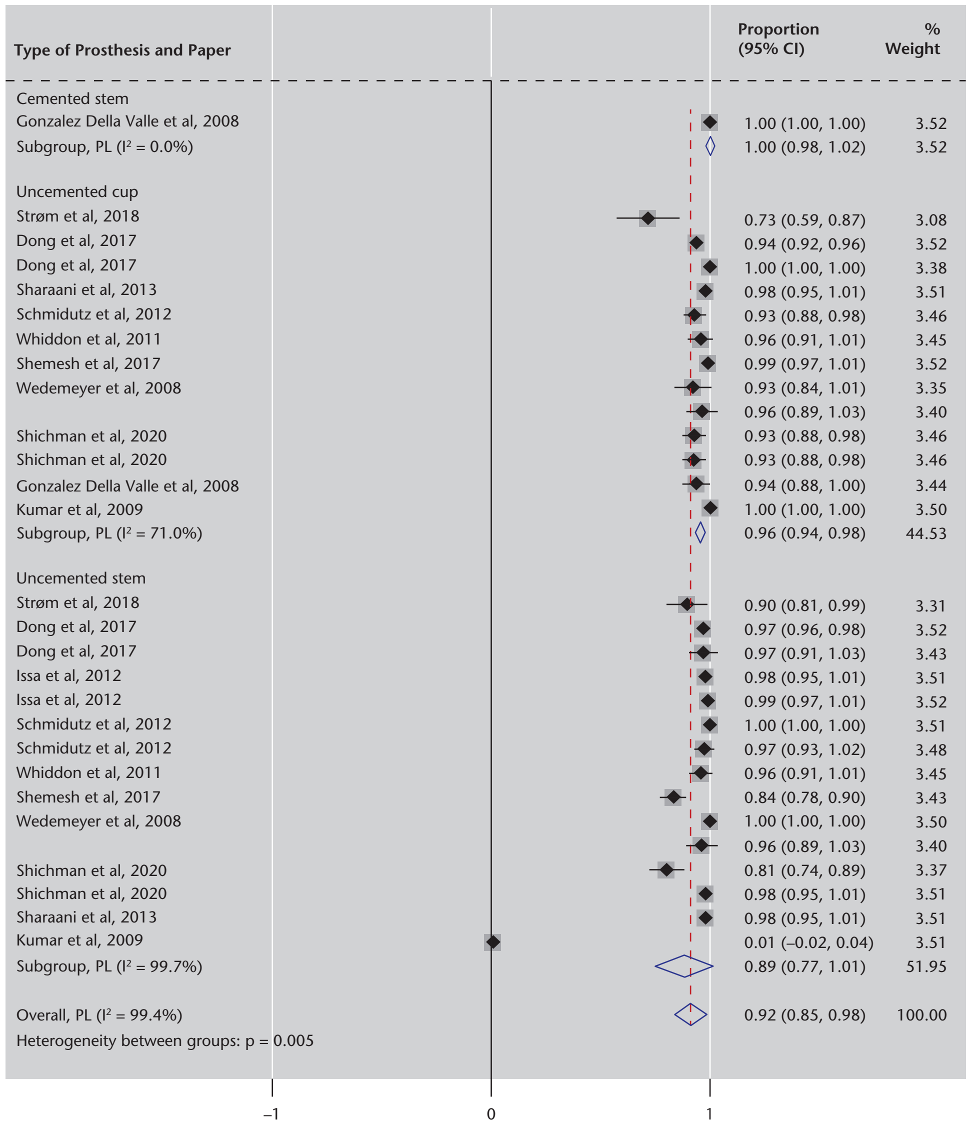


Fig. 3 Forest plot for one-size difference (±1) accuracy meta-analysis results.

Note. CI, confidence interval; PL, profile likelihood.



NOTE: Weights and between-subgroup heterogeneity test are from random-effects model; continuity correction applied to studies with zero cells

Fig. 4 Forest plot for two-size difference accuracy (±2) meta-analysis results.

Note. CI, confidence interval; PL, profile likelihood.

different magnification techniques within the same study. X-ray magnification reference objects are considered standard practice because they allow the calculation of an accurate and reliable magnification factor. In three of the studies no X-ray magnification reference objects were used in the preoperative X-ray procedure. In two of these studies a manual preoperative X-ray magnification technique was used instead. In the studies that did use a magnification reference object, there was significant variability in the positioning of the reference object, with the most common location being adjacent to the greater trochanter (13 studies). In some studies, the location of the reference object was not clearly specified (e.g. 'placed at bone level').

The study-specific limitations have been presented in the critical appraisal of the quality of evidence (Table 2). One of the more generic limitations, which was not specific to any particular study, was the fact that there was no consistent, objective method for determining whether or not the size of prosthesis that had actually been implanted was suitable. Consequently, most of these studies were investigating the accuracy of templating in prosthesis size prediction based upon the implanted prosthesis, regardless of whether or not it was suitable, rather than the accuracy of templating in determining the correct size, shape and position of the prosthesis. For this reason, surgical inaccuracy, rather than templating inaccuracy, may well have negatively affected the accuracy measurements, and

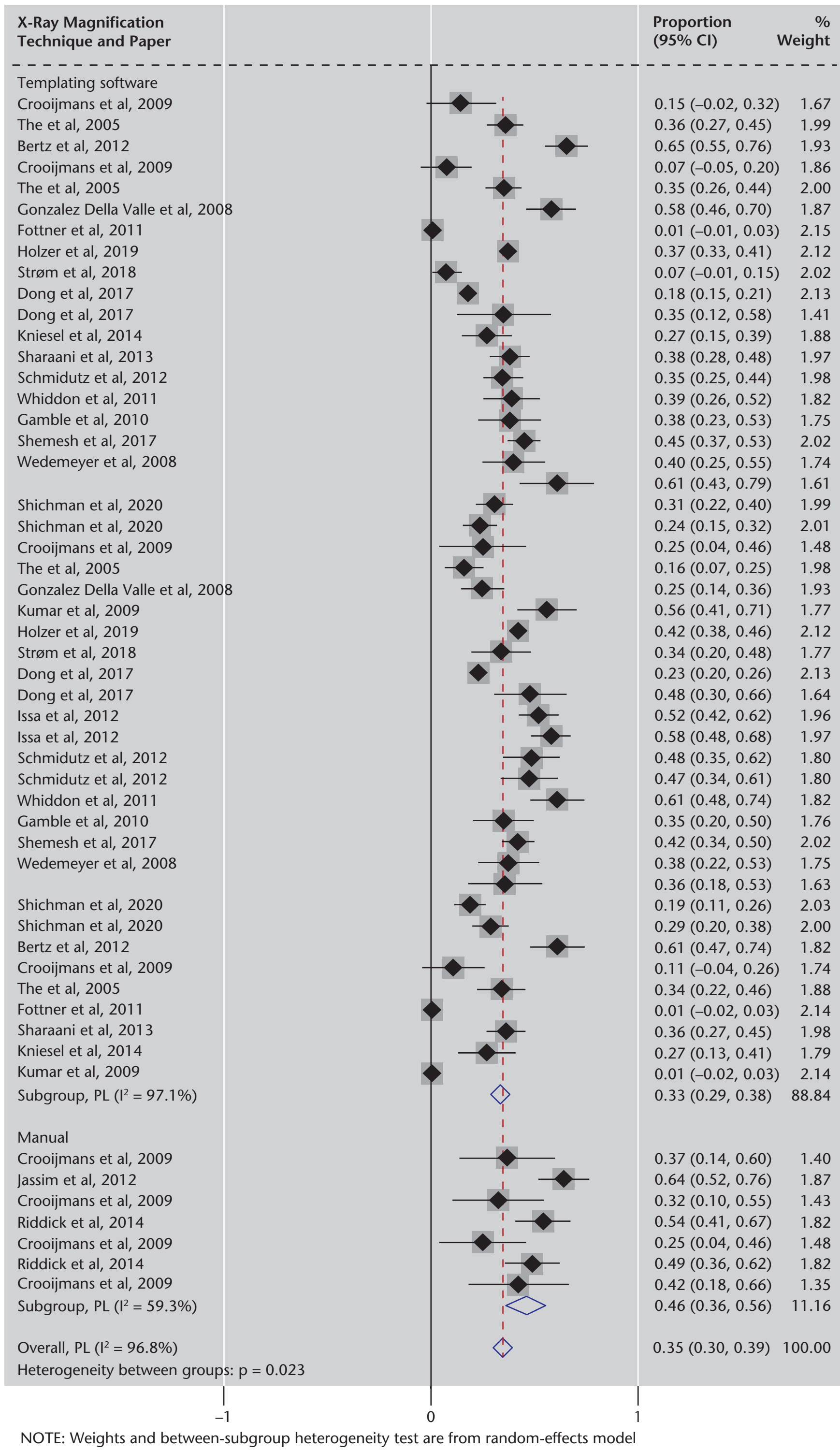


Fig. 5 Forest plot for exact size accuracy meta-analysis results: subgroup analysis for X-ray magnification technique.

Note. CI, confidence interval; PL, profile likelihood.

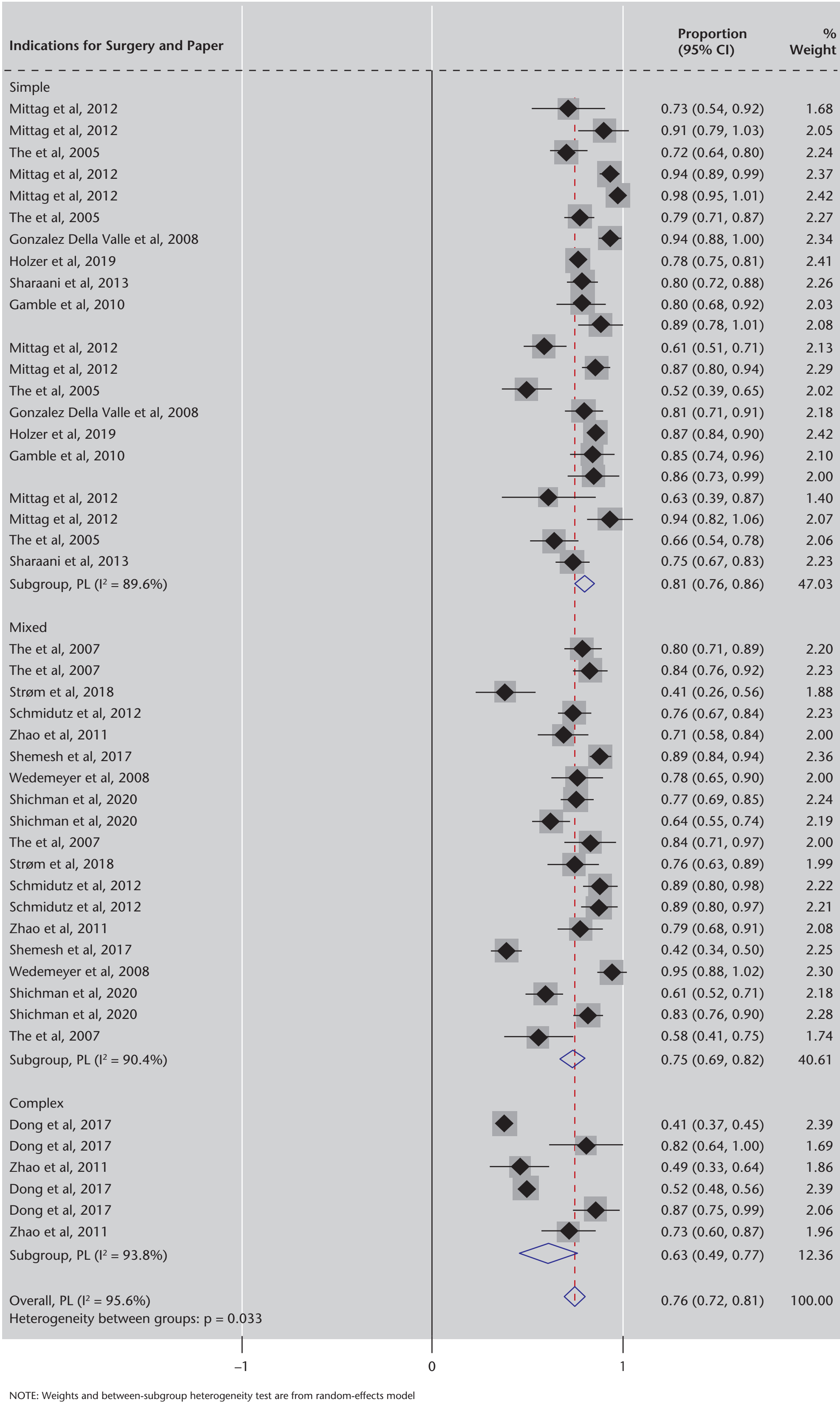


Fig. 6 Forest plot for one-size difference (±1) accuracy meta-analysis results: subgroup analysis for indication for surgery.
Note. CI, confidence interval; PL, profile likelihood.

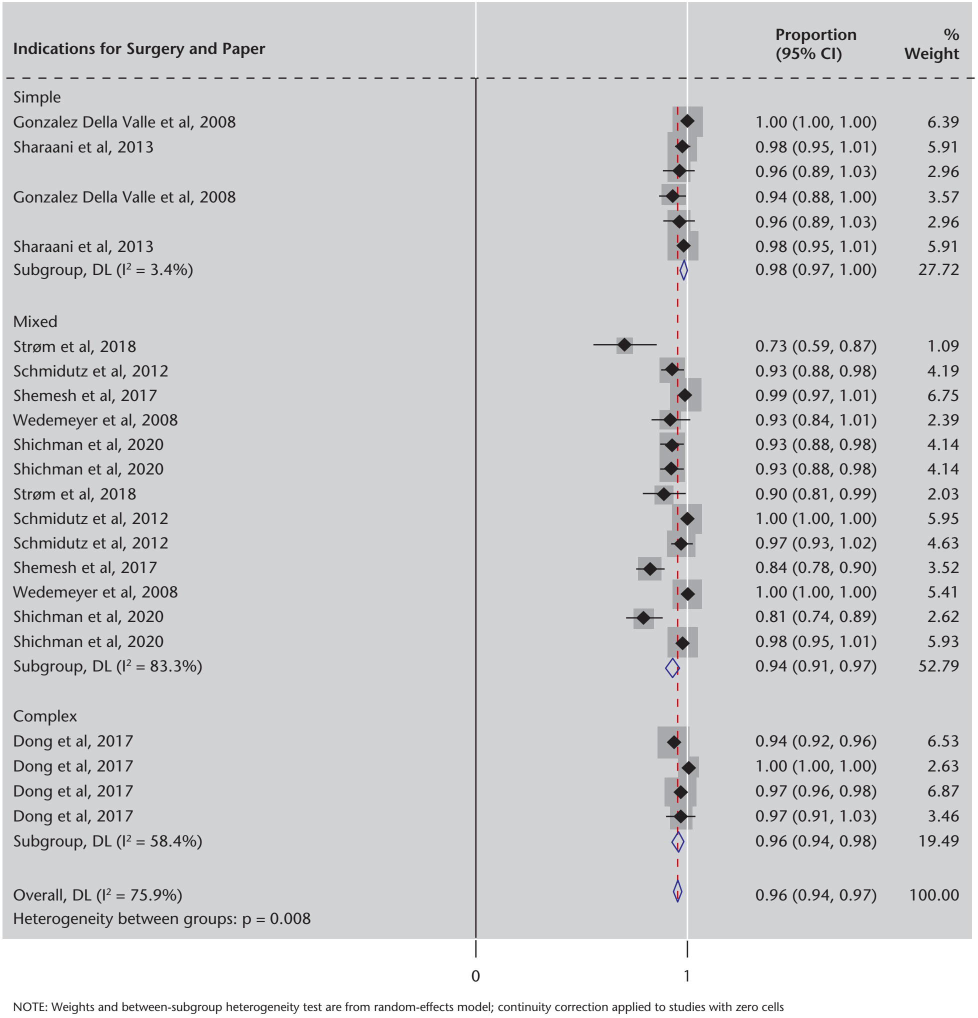
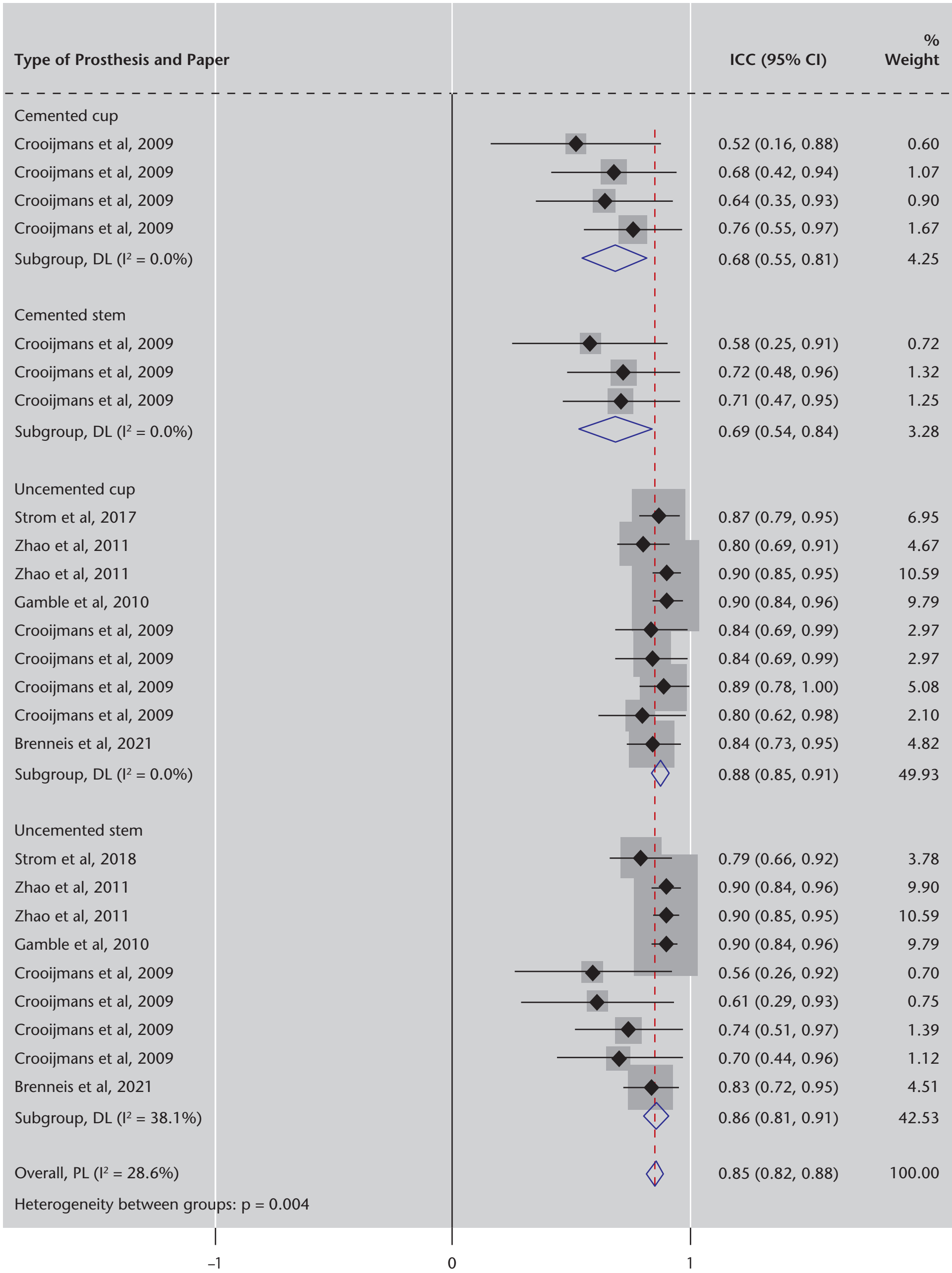


Fig. 7 Forest plot for two-size difference accuracy (±2) meta-analysis results: subgroup analysis for indication for surgery.
Note. CI, confidence interval; DL, DerSimonian-Laird.

therefore, the effect sizes in some of the studies. In the study by Gamble et al, the inclusion criteria only included patients with appropriately sized and positioned THA implants on postoperative radiographic analysis, and this supported a potential reduction of the effect of surgical inaccuracy on the accuracy of templating results.[22] A detailed assessment of the size, shape and position of the implants on postoperative radiographs should therefore be used as the gold-standard methodology for any future studies investigating the accuracy of preoperative templating, because all three measurements need to be satisfied in order to restore the original hip biomechanics.[7]

Conclusion

Although greater for cemented implants, the accuracy of digital 2D templating in prosthesis size prediction was high (> 70% for within one prosthesis size) for both cemented and uncemented THA implants, supporting its continued routine use in preoperative planning, irrespective of the method of fixation. The intra-observer reliability was greater than the inter-observer reliability for uncemented implants, suggesting that it should be the surgeon performing the procedure who also performs the templating.



NOTE: Weights and between-subgroup heterogeneity test are from random-effects model

Fig. 8 Forest plot for inter-observer reliability meta-analysis results.

Note. ICC, intraclass correlation coefficients; CI, confidence interval; DL, DerSimonian-Laird.

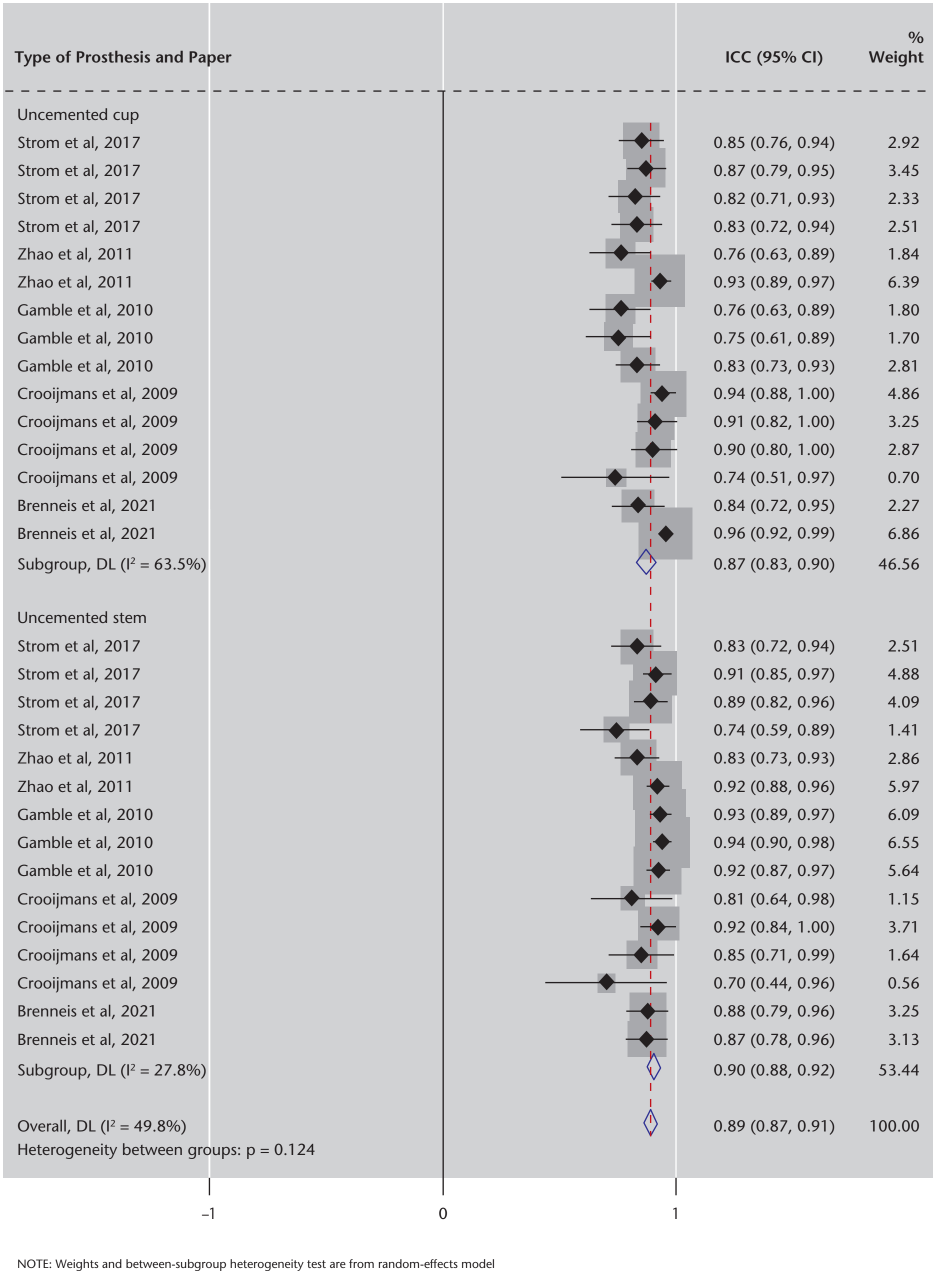


Fig. 9 Forest plot for intra-observer reliability meta-analysis results.

Note. ICC, intraclass correlation coefficients; CI, confidence interval; DL, DerSimonian-Laird.

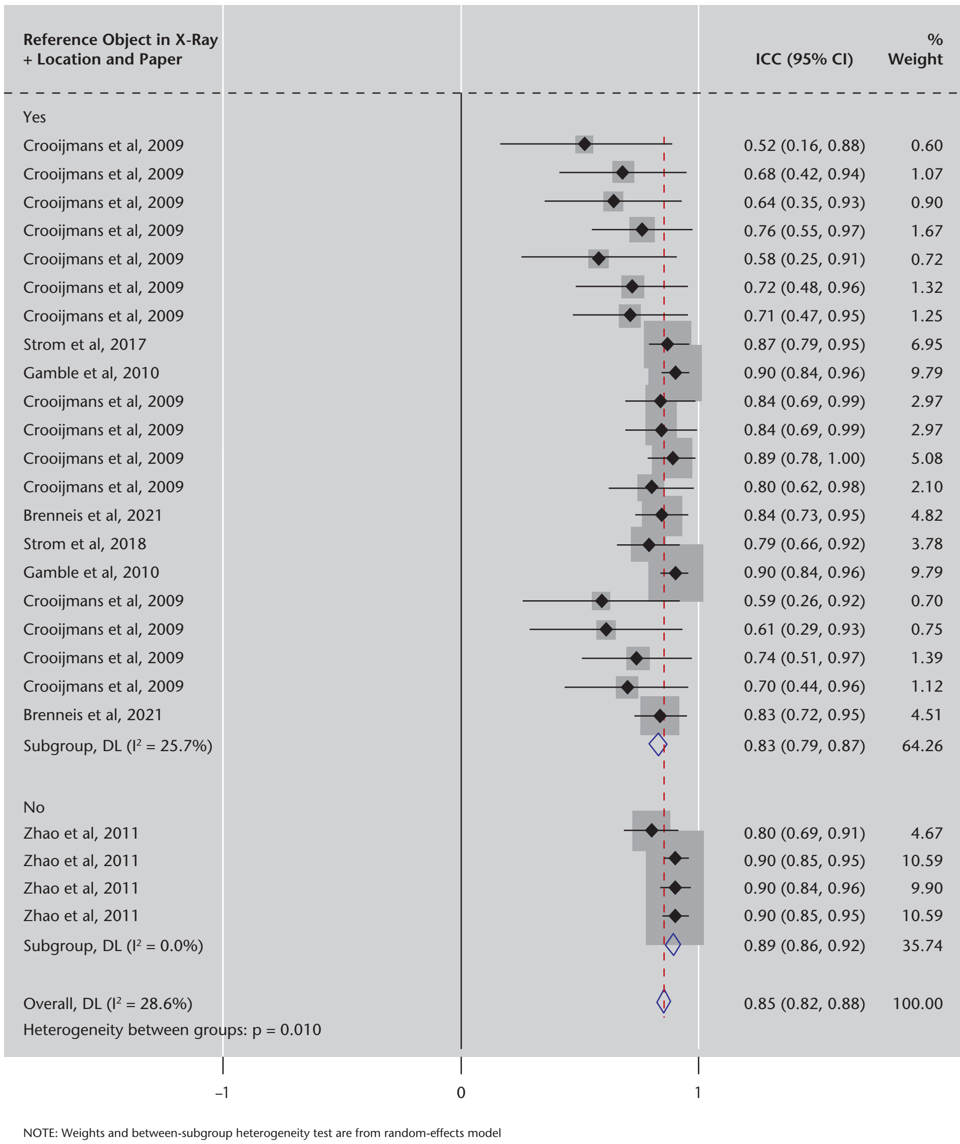


Fig. 10 Forest plot for inter-observer reliability meta-analysis results: subgroup analysis for X-ray reference object.
Note. ICC, intraclass correlation coefficients; CI, confidence interval; DL, DerSimonian-Laird.

AUTHOR INFORMATION

[1]Academic Surgical Unit, South West London Elective Orthopaedic Unit, Epsom, Surrey, UK.
[2]Kingston University and St George's University of London, Tooting, London, UK.

Correspondence should be sent to: Joshua B.V. Smith, Academic Surgical Unit, South West London Elective Orthopaedic Centre, Epsom General Hospital, Dorking Rd, Epsom KT18 7EG, UK.
Email: jbvsmith1@hotmail.com

ICMJE CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest relevant to this work.

FUNDING STATEMENT

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES

1. **Della Valle AG, Padgett DE, Salvati EA.** Preoperative planning for primary total hip arthroplasty. *J Am Acad Orthop Surg* 2005;13:455–462.

2. **Jassim SS, Ingham C, Keeling M, Wimhurst JA.** Digital templating facilitates accurate leg length correction in total hip arthroplasty. *Acta Orthop Belg* 2012;78:344–349.

3. **Shaarani SR, McHugh G, Collins DA.** Accuracy of digital preoperative templating in 100 consecutive uncemented total hip arthroplasties: a single surgeon series. *J Arthroplasty* 2013;28:331–337.

4. **Eggli S, Pisan M, Müller ME.** The value of preoperative planning for total hip arthroplasty. *J Bone Joint Surg [Br]* 1998;80-B:382–390.

5. **The B, Verdonschot N, van Horn JR, van Ooijen PM, Diercks RL.** Digital versus analogue preoperative planning of total hip arthroplasties: a randomized clinical trial of 210 total hip arthroplasties. *J Arthroplasty* 2007;22:866–870.

6. **National Institute for Health Research (NIHR) PROSPERO (International Prospective Register of Systematic Reviews).** https://www.crd.york.ac.uk/prospero/ (date last accessed 30 August 2021).

7. **Colombi A, Schena D, Castelli CC.** Total hip arthroplasty planning. *EFORT Open Rev* 2019;4:626–632.

8. **Hsu AR, Kim JD, Bhatia S, Levine BR.** Effect of training level on accuracy of digital templating in primary total hip and knee arthroplasty. *Orthopedics* 2012;35:e179–e183.

9. **PRISMA guidelines.** http://www.prisma-statement.org/PRISMAStatement/Checklist (date last accessed 29 March 2021).

10. **Institute of Health Economics.** https://www.ihe.ca/publications/ihe-quality-appraisal-checklist-for-case-series-studies (date last accessed 19 March 2021).

11. **Brice R.** CASP checklists. CASP – Critical Appraisal Skills Programme. https://casp-uk.net/casp-tools-checklists/ (date last accessed 6 April 2021).

12. **Borenstein M, Hedges LV, Higgins JPT, Rothstein HR.** *Introduction to meta-analysis*. Chichester, UK: John Wiley & Sons, 2009.

13. **Kontopantelis E, Reeves D.** Performance of statistical methods for meta-analysis when true study effects are non-normally distributed: a comparison between DerSimonian-Laird and restricted maximum likelihood. *Stat Methods Med Res* 2012;21:657–659.

14. **Fisher D, Harris R, Bradburn M, Deeks J, Harbord R, Altman D, et al.** *METAN: Stata module for fixed and random effects meta-analysis*. Statistical Software Components. Boston College Department of Economics, 2021. https://ideas.repec.org/c/boc/bocode/s456798.html (date last accessed 29 March 2021).

15. **PRISMA flow diagram.** http://prisma-statement.org/prismastatement/flowdiagram (date last accessed 24 March 2021).

16. **The B, Diercks RL, van Ooijen PM, van Horn JR.** Comparison of analog and digital preoperative planning in total hip and knee arthroplasties: a prospective study of 173 hips and 65 total knees. *Acta Orthop* 2005;76:78–84.

17. **Wedemeyer C, Quitmann H, Xu J, Heep H, von Knoch M, Saxler G.** Digital templating in total hip arthroplasty with the Mayo stem. *Arch Orthop Trauma Surg* 2008;128:1023–1029.

18. **González Della Valle A, Comba F, Taveras N, Salvati EA.** The utility and precision of analogue and digital preoperative planning for total hip arthroplasty. *Int Orthop* 2008;32:289–294.

19. **Kosashvili Y, Shasha N, Olschewski E, et al.** Digital versus conventional templating techniques in preoperative planning for total hip arthroplasty. *Can J Surg* 2009;52:6–11.

20. **Crooijmans HJA, Laumen AMRP, van Pul C, van Mourik JBA.** A new digital preoperative planning method for total hip arthroplasties. *Clin Orthop Relat Res* 2009;467:909–916.

21. **Kumar PGA, Kirmani SJ, Humberg H, Kavarthapu V, Li P.** Reproducibility and accuracy of templating uncemented THA with digital radiographic and digital TraumaCad templating software. *Orthopedics* 2009;32:815.

22. **Gamble P, de Beer J, Petruccelli D, Winemaker M.** The accuracy of digital templating in uncemented total hip arthroplasty. *J Arthroplasty* 2010;25:529–532.

23. **Whiddon DR, Bono JV, Lang JE, Smith EL, Salyapongse AK.** Accuracy of digital templating in total hip arthroplasty. *Am J Orthop* 2011;40:395–398.

24. **Zhao X, Zhu Z-A, Zhao J, et al.** The utility of digital templating in total hip arthroplasty with Crowe type II and III dysplastic hips. *Int Orthop* 2011;35:631–638.

25. **Fottner A, Steinbrück A, Sadoghi P, Mazoochian F, Jansson V.** Digital comparison of planned and implanted stem position in total hip replacement using a program form migration analysis. *Arch Orthop Trauma Surg* 2011;131:1013–1019.

26. **Gallart X, Daccach JJ, Fernández-Valencia JÁ, García S, Bori G, Rios J, et al.** Study of the consistency of a system for preoperative planning digital in total arthroplasty of the hip. *Rev Esp Cir Ortop Traumatol* 2012;56:471–477.

27. **Issa K, Pivec R, Boyd B, Wuestemann T, Nevelos J, Mont MA.** Comparing the accuracy of radiographic preoperative digital templating for a second- versus a first-generation THA stem. *Orthopedics* 2012;35:1028–1034.

28. **Schmidutz F, Steinbrück A, Wanke-Jellinek L, Pietschmann M, Jansson V, Fottner A.** The accuracy of digital templating: a comparison of short-stem total hip arthroplasty and conventional total hip arthroplasty. *Int Orthop* 2012;36:1767–1772.

29. **Bertz A, Indrekvam K, Ahmed M, Englund E, Sayed-Noor AS.** Validity and reliability of preoperative templating in total hip arthroplasty using a digital templating system. *Skeletal Radiol* 2012;41:1245–1249.

30. **Mittag F, Ipach I, Schaefer R, Meisner C, Leichtle U.** Predictive value of preoperative digital templating in THA depends on the surgical experience of the performing physician. *Orthopedics* 2012;35:e144–e147.

31. **Riddick A, Smith A, Thomas DP.** Accuracy of preoperative templating in total hip arthroplasty. *J Orthop Surg (Hong Kong)* 2014;22:173–176.

32. **Kniesel B, Konstantinidis L, Hirschmüller A, Südkamp N, Helwig P.** Digital templating in total knee and hip replacement: an analysis of planning accuracy. *Int Orthop* 2014;38:733–739.

33. **Hafez MA, Ragheb G, Hamed A, Ali A, Karim S.** Digital templating for THA: a simple computer-assisted application for complex hip arthritis cases. *Biomed Tech (Berl)* 2016;61:519–524.

34. **Shemesh SS, Robinson J, Keswani A, Bronson MJ, Moucha CS, Chen D.** The accuracy of digital templating for primary total hip arthroplasty: is there a difference between direct anterior and posterior approaches? *J Arthroplasty* 2017;32:1884–1889.

35. Strøm NJ, Pripp AH, Reikerås O. Templating in uncemented total hip arthroplasty: on intra- and interobserver reliability and professional experience. *Ann Transl Med* 2017;5:43.

36. Dong N, Yang C, Li S-Q, Gao Y-H, Liu J-G, Qi X. A novel digital templating methodology for arthroplasty: experience from patients with osteonecrosis of the femoral head. *Hip Int* 2017;27:82–86.

37. Strøm NJ, Reikerås O. Templating in uncemented THA: on accuracy and postoperative leg length discrepancy. *J Orthop* 2018;15:146–150.

38. Holzer LA, Scholler G, Wagner S, Friesenbichler J, Maurer-Ertl W, Leithner A. The accuracy of digital templating in uncemented total hip arthroplasty. *Arch Orthop Trauma Surg* 2019;139:263–268.

39. Montiel V, Troncoso S, Valentí-Azcárate A, Valentí-Nin JR, Lamo-Espinosa JM. Total hip arthroplasty digital templating: size predicting ability and interobserver variability. *Indian J Orthop* 2020;54:840–847.

40. Shichman I, Factor S, Shaked O, et al. Effects of surgeon experience and patient characteristics on accuracy of digital pre-operative planning in total hip arthroplasty. *Int Orthop* 2020;44:1951–1956.

41. Brenneis M, Braun S, van Drongelen S, et al. Accuracy of preoperative templating in total hip arthroplasty with special focus on stem morphology: a randomized comparison between common digital and three-dimensional planning using biplanar radiographs. *J Arthroplasty* 2021;36:1149–1155.