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A systematic review and meta-analysis of trainee- *versus* consultant surgeon-performed elective total hip arthroplasty

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- Total hip arthroplasty (THA) is one of the most commonly performed orthopaedic procedures. Some concern exists that trainee-performed THA may adversely affect patient outcomes. The aim of this meta-analysis was to compare outcomes following THA performed by surgical trainees and consultant surgeons.
- A systematic search was performed to identify articles comparing outcomes following trainee- *versus* consultant-performed THA. Outcomes assessed included rate of revision surgery, dislocation, deep infection, mean operation time, length of hospital stay and Harris Hip Score (HHS) up to one year. A meta-analysis was conducted using odds ratios (ORs) and weighted mean differences (WMDs). A subgroup analysis for supervised trainees *versus* consultants was also performed.
- The final analysis included seven non-randomized studies of 40 810 THAs, of which 6393 (15.7%) were performed by trainees and 34 417 (84.3%) were performed by consultants. In total, 5651 (88.4%) THAs in the trainee group were performed under supervision. There was no significant difference in revision rate between the trainee and consultant groups (OR 1.09; $p = 0.51$). Trainees took significantly longer to perform THA compared with consultants (WMD 12.9; $p < 0.01$). The trainee group was associated with a lower HHS at one year compared with consultants (WMD -1.26; $p < 0.01$). There was no difference in rate of dislocation, deep infection or length of hospital stay between the two groups.
- The present study suggests that supervised trainees can achieve similar clinical outcomes to consultant surgeons, with a slightly longer operation time. In selected patients, trainee-performed THA is safe and effective.

Keywords: total hip arthroplasty; surgical training; supervision

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Introduction

Total hip arthroplasty (THA) is one of the most commonly performed operations worldwide. Demand for THA is set to increase over the next decade with a 174% increase in the USA estimated by 2030,[1,2] largely due to longer life expectancy, an ageing population and higher functional demand in the developed world.[3] Training future orthopaedic surgeons is clearly crucial if supply is to meet demand. However, such training raises several conflicting issues. Although trainees must have adequate operative experience to be deemed competent in a procedure, this must be balanced with increasing scrutiny of outcomes, the widespread use of joint registries and pressure on surgical teams to maximize efficiency. Concerns have been raised that trainee-performed operations may be associated with poorer outcomes for patients, a reduction in efficiency and a consequent rise in healthcare delivery costs.[4-8] Schoenfeld et al conducted a retrospective review of outcomes using registry data for 12 commonly performed orthopaedic operations, noting a mild to moderate risk of complications for operations involving a resident.[5] Similarly, Marston et al compared outcomes following trainee- and consultant-performed THA, noting a higher revision rate among trainee-performed procedures.[9] The growing use of validated simulation packages for training has helped to familiarize trainees with orthopaedic procedures and offset the learning curve for THA.[10] However, there is no substitute for gaining competence by repetitively undertaking a procedure.[11]

The aim of the present study is to compare outcomes following trainee- and consultant-performed THA by analysing the existing evidence relating to this important question.

Methods

Study selection

This study was registered with the PROSPERO international database of systematic reviews (CRD42018086012) and followed the Preferred Reporting Items of Systematic Reviews and Meta-analyses (PRISMA) guidelines.[12] A systematic search of all published literature was performed using The Medical Literature Analysis and Retrieval System Online (MEDLINE via PubMed), Excerpta Medica (EMBASE), the Ovid database, Google and Google Scholar, and the Cochrane Controlled Trials Register. The following items were used for the search, both alone and in various combinations: 'total hip arthroplasty'; 'total hip replacement'; 'resident training'; 'resident performed'; 'trainee'; 'trainee performed'; 'outcomes'; 'trainee lead'; and 'functional outcome'. The 'related articles' function in PubMed was used to widen the search. The titles, abstracts and citations resulting from each search were systematically scanned by the authors and assessed for inclusion. A minimum of two authors conducted a manual search of all references. Reviewers independently assessed full texts to determine whether the study met our inclusion criteria. Date limits were between January 2000 and October 2017. No language restrictions were imposed.

Inclusion and exclusion criteria

The following inclusion criteria were applied:

1) compared outcomes following trainee-performed and consultant-performed THA in an elective setting;
2) trainees must have performed part of or the whole procedure. Studies which reported outcomes for resident involvement in the procedure only (i.e. participated as an assistant but did not perform part of or the whole procedure) were excluded. A consultant was defined as a board-certified, independently operating surgeon;
3) randomized controlled trial, prospective observational or retrospective study;
4) reports data on at least one of the primary or secondary outcomes;
5) a minimum sample size of ten patients in each group.

Studies were excluded from the analysis if:

1) extractable data relating to any of the outcomes were not available;
2) the study reported outcomes for operations involving trainees as assistants;
3) the study did not directly compare outcomes for consultant- and trainee-performed THA;
4) the study was a review article, correspondence or conference abstract.

Data extraction and outcomes

Two authors independently identified studies for inclusion and extracted data for the outcomes. Discrepancies in extraction of data were resolved by re-examination of the literature until consensus was achieved. A standardized data extraction spreadsheet was used by each of the reviewers to ensure consistency in the method of data extraction. The primary outcome for the meta-analysis was the rate of revision surgery following THA. Secondary outcomes included the rate of dislocation, rate of deep tissue infection, mean operation time, length of hospital stay and Harris Hip Score (HSS) up to one year. Where meta-analysis was not possible due to insufficient data or unacceptable clinical heterogeneity, a qualitative analysis and review of the available data were performed.

Statistical analysis

Dichotomous variables were compared using odds ratios (ORs) with 95% confidence intervals (CI). The OR was defined as the probability of an event occurring in the trainee group compared with the consultant group. Continuous variables were compared using weighted mean differences (WMD) with 95% CIs. The Mantel–Haenszel method was used for the meta-analysis.[13]

Heterogeneity was assessed using the chi-squared (X^2) test, with $p < 0.050$ being regarded as significant. The I^2 statistic was also used, with < 50% being regarded as a low degree of heterogeneity. In such cases, a fixed effects (FE) model of meta-analysis was used. Studies with $I^2 >$ 50% were considered to be associated with a high degree of heterogeneity and a random effects model was applied.[14] Random effects models assume that variation in effect size between studies exists, and account for differences in study population, co-morbidities and surgical protocol which would otherwise lead to a significant risk of bias.

Statistical analysis was performed using Review Manager 5.3 (The Cochrane Collaboration, Copenhagen, Denmark).

Quality assessment and sensitivity analysis

A quality assessment of all studies was performed using the Newcastle-Ottawa Scale (NOS) for non-randomized studies. High-quality studies were defined as scoring ≥ 7 on the NOS. A planned sensitivity analysis was performed for high-quality studies and a separate subgroup analysis

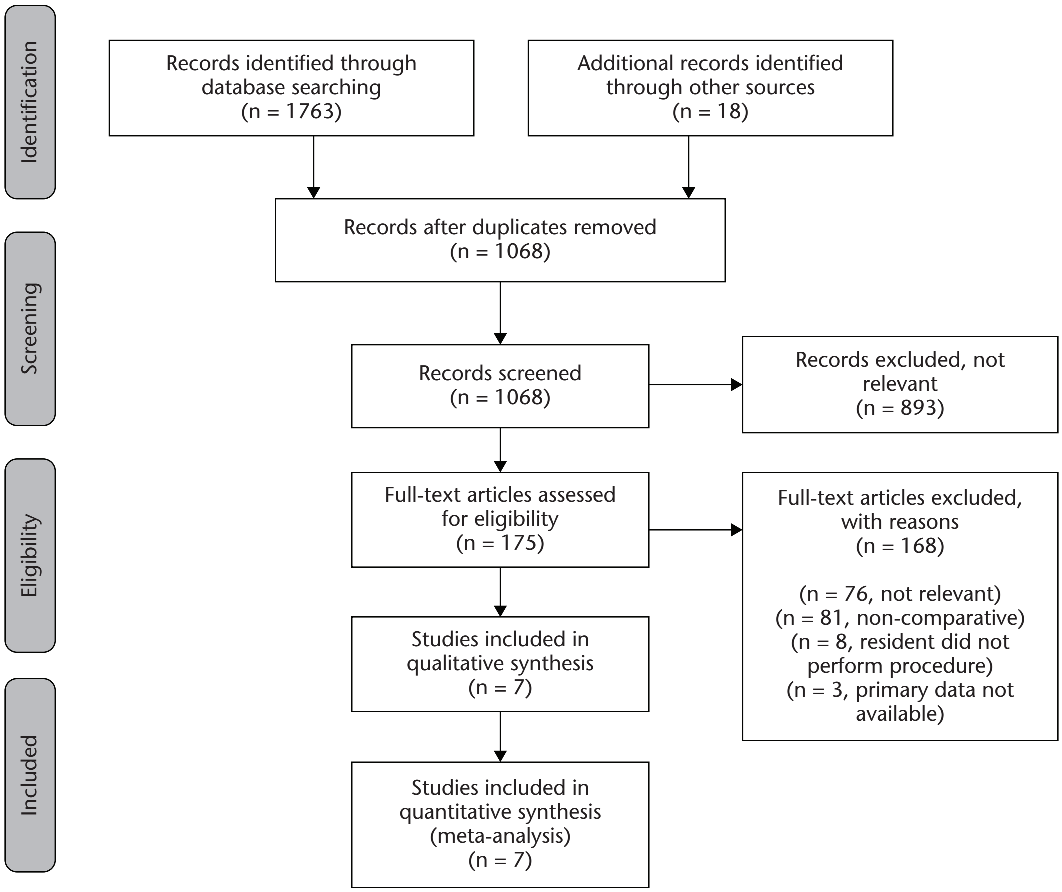


Fig. 1 PRISMA flow diagram for included studies.

was performed comparing outcomes for supervised trainees *versus* consultants.

Results

Eligible studies

After exclusions, seven studies were included in the final analysis (Fig. 1), involving 40 810 THAs, of which 6393 (15.7%) were performed by trainee surgeons and 34 417 (84.1%) were performed by consultant surgeons (Table 1). Two of the included studies were prospective, non-randomized studies and five studies were retrospective. A total of 5651 (88.4%) THAs within the trainee group were performed under supervision of consultant surgeons. One study reported outcomes following minimally invasive THA.[15] Dates of publication for included studies ranged from 2004 to 2017. All studies were performed in developed-world settings, with four British, one German, one North American and two Australasian studies. The mean age of patients was in the range of 65.9 to 70.0 years for the trainee group compared with 63.8 to 70.0 years for the consultant group (Table 2). In one study, trainees operated on significantly older patients when compared with consultants (70 years *versus* 66 years, respectively; $p < 0.01$).[16] In the remaining studies, there was no significant difference in baseline age or ASA grade between the two groups. The mean follow-up interval for the primary outcome was 42 months (Table 1).

Meta-analysis was conducted for the following outcomes: rate of revision surgery; rate of dislocation; rate of deep infection; operation time; length of hospital stay; and HHS at six months. Two studies defined supervision as having the consultant scrubbed with the trainee and acting as first assistant.[16,17] The remaining studies did not give a clear definition of supervision (Table 3). Although the definition of a trainee varied between studies, all were on a recognized training programme for orthopaedic surgery. Two studies separated trainees into junior and senior groups with 40.7% (215/528)[18] and 48.3% (138/286)[19] being assigned to the junior trainee groups. There was wide variation in implant choice and surgical technique between studies, described in Table 4. Woolson et al compared operations done in the private (by consultants) and public (by trainees) sectors. While the components used were the same, there was a difference in the utilization of screw fixation for the acetabular component

Table 1. Characteristics of included studies

References	Year	Journal	Location	Study type	Comparison	Trainee (n)	Consultant (n)	FU/ months	Outcome measures
Inglis	2012	*Journal of Surgical Education*	New Zealand	Retrospective, registry data	Consultant *vs* supervised or unsupervised trainee	4049	30344	72	Revision rates; OHS
Moran	2004	*Journal of Arthroplasty*	UK	Prospective, non-randomized	Supervised trainee *vs* consultant	139	397	18	HHS at 6 and 18 months; blood loss; transfusion requirements; revision; dislocation; death; acetabular and femoral component alignment; cementation
Palan	2009	*BJJ*	UK	Prospective, non-randomized	Trainer *vs* trainee	528	973	60	Revision rate; change in OHS; dislocation; length of stay; operating time
Reidy	2016	*BJJ*	UK	Retrospective	Consultant *vs* senior or junior trainee	286	584	144	HHS; dislocation; length of stay; deep infection
Weber	2017	*Nature Scientific Reports*	Germany	Retrospective, registry data	Senior surgeon *vs* supervised trainee	240	768	12	EQ-5D Score; WOMAC score; dislocation; operating time; deep infection; intraoperative fracture
Wilson	2016	*ANZ J Surg*	Australia	Retrospective	Consultant *vs* trainee, junior *vs* senior trainee	1032	1240	12	Surgical complication; medical complication; wound complication; transfusion; readmission
Woolson	2007	*JBJS*	USA	Retrospective	Supervised trainee *vs* consultant	119	111	49	HHS; length of stay; operating time; units of transfusion required; estimated blood loss; femoral component alignment: varus/neutral/ valgus; femoral component fit: good/ fair/poor

Table 2. Study demographics

	Patient characteristics								
References	Age	Mean	SD	Gender Male/Total	ASA 1	2	3	4	Notes
Inglis[21]	N/A			N/A					
Moran[16]	Trainee	70	9	50/139					Trainees operated on significantly older patients ($p < 0.001$)
	Consultant	66	11	155/397					
Palan[18]	Trainee	68.8	17	N/A					
	Consultant	68	18						
Reidy[19]	N/A			N/A					
Weber[15]	Trainee	65.9	10.1	121/240	27	125	85	3	No significant difference in age, gender, ASA on multivariate analysis
	Consultant	63.8	10.8	365/768	142	411	212	3	
Wilson[20]	Trainee	69	3.25	406/1032	31	606	376	19	No significant difference in age, gender, ASA on multivariate analysis
	Consultant	70	3.5	517/1240	57	698	465	20	
Woolson[17]	N/A			N/A					

(3/111 consultant, 98/119 *versus* press fit for the rest).[17] Regarding approaches, one study reported that both consultants and trainees used the anterolateral approach for all cases.[16] One study reported on the anterolateral minimally invasive approach,[15] again for both consultant and trainee groups in all cases. In the studies where differing approaches were used, the anterolateral approach predominated (Table 4). Of the data available in the three studies where differing approaches were employed, consultants used the anterolateral approach in 57% (1601/2797) of cases and the posterior approach in 31% (871/2791) of cases. Trainees used the anterolateral approach in 72.6% (1215/1697) of cases and the posterior approach in 28% (476/1697) of cases. One of these studies also reported that 4% (52/1240) of consultants used the anterior approach *versus* 0.7% (6/1032) of trainees.

Risk of bias assessment

Each study was assessed for quality using the NOS tool for non-randomized studies. Studies were deemed to be of high quality if they scored ≥ 7 out of 9 points on the NOS. Results of the quality assessment are displayed in Table 5. Five out of seven studies were deemed to be of high quality.[15,16,18-20]

Comparison of outcomes

Comparison of rate of revision surgery

Data from five studies were included in the meta-analysis for the rate of revision surgery. There was no difference in

Table 3. Description of supervision characteristics for included studies

Study	Trainee group				Trainee (n)				
	Definition of trainee	Level of involvement	Definition of supervision	Definition of senior trainee	Total	Supervised	Unsupervised	Junior	Senior
Inglis	Unclear	Performed / primary operator	Unknown	N/A	4049	2982	1067		
Moran	Year 1 to 4 registrar (UK)	Performed / primary operator	Trainer scrubbed and acting as first assistant. Intervenes if trainee about to make a critical mistake that could jeopardize the final outcome	N/A	139	139	N/A		
Palan	All grades registrar (UK)	Performed / primary operator	Unknown	Post FRCS Exam	528	528	N/A	215	313
Reidy	Year 1 to 6 registrar (UK)	Performed / primary operator	Unclear	Year 4 to 6 registrar	286	241	44	138	148
Weber	Year 3 to 5 of surgical training (Germany)	Performed whole procedure / primary operator	Unclear	N/A	240	240	N/A		
Wilson	Unclear	Performed / primary operator	Unclear	N/A	1032	Unclear	Unclear		
Woolson	Resident or joint replacement fellow (USA)	Performed either femoral or acetabular component, other performed by attending	Attending present for entire procedure on trainee side of table	N/A	109	109	N/A		

Table 4. Surgical techniques

References	Implant				Approach	
	Femoral component	Acetabular component	Head	Acetabular screw fixation	Consultants	Trainees
Inglis	N/A	N/A			N/A	N/A
Moran	Cemented Charnley (De Puy)	Cemented Charnley (De Puy)			Anterolateral	Anterolateral
Palan	Cemented Exeter (Stryker)	Cementless and cemented Exeter and Charnley			Anterolateral 57% (402) Posterior 43% (301)	Anterolateral 77% (291) Posterior 23% (88)
Reidy	Exeter 285, Charnley 209 CPT 190 Aesculap 103 Lubinus 50 Mayo 21 ABG I 17 Biomet 2 ABG II 1 Birmingham Resurfacing 1	Not recorded 316 Exeter polyethylene cup 160 Trilogy 149 Aesculap 102 ZCA 78 Ogee 38 ABG II 15 TOP 13 Charnley Elite plus Ogee 5 Birmingham 1 ABG 1 Charnley LPW 1	Not recorded 356 Stainless steel 335 Cobalt chrome 167 Ceramic 21		Anterolateral 88% (510) Posterior 12% (71)	Anterolateral 91% (260) Posterior 9% (26)
Weber	Uncemented Corail Uncemented Trilock (Depuy)	Pinnacle Cup (Depuy)			Minimally invasive anterolateral	Minimally invasive anterolateral
Wilson	Unrecorded	Unrecorded			Anterolateral 56% (689) Posterior 40% (499) Anterior 4% (52)	Anterolateral 64.3% (664) Posterior 35% (362) Anterior 0.7% (6)
Woolson	Uncemented AML and Replica Cemented Endurance (Depuy)	Uncemented Duraloc (Depuy)		Consultant group 3/111 Trainee group 98/119		

rate of revisions between the two groups (OR 1.09; 95% CI 0.85 to 1.39; p = 0.51, Table 6, Fig. 2a).

Comparison of rate of deep infection

The rate of deep infection was reported by five studies. There was no difference in the infection rate between consultants and trainees (OR 1.49; 95% CI 0.93 to 2.41; p = 0.10, Fig. 3). These results were associated with low heterogeneity ($I^2 = 0\%$).

Comparison of rate of dislocation

Six studies compared rates of dislocation following THA between the two groups. There was no overall difference in dislocation rate (OR 0.96; 95% CI 1.76 to 1.67; p = 0.10,

Table 5. Newcastle-Ottawa Scale for risk of bias assessment

References	Selection Representativeness	Selection of non-exposed cohort	Ascertainment of exposure	Demonstration outcome present before exposure	Comparability	Outcome Outcome assessment	Follow-up Length	Follow-up Adequacy	Total
Inglis	No description of cohort derivation	No description of non-exposed cohort	*	Pre-operative OHS not available	* *	*	*	*	6/9
Moran	*	Patients operated on by trainees were older	*	*	* *	*	*	*	8/9
Palan	*	*	*	*	No description of adjustment for confounders in analysis	*	*	*	7/9
Reidy	*	*	*	*	* *	*	*	*	9/9
Weber	*	*	*	*	* *	*	*	*	9/9
Wilson	*	*	*	N/A	* *	*	*	*	8/9
Woolson	*	Male:female ratio difference	*	No description of pre-operative HHS scores	No description of adjustment for confounders in analysis	*	*	*	5/8

Table 6. Results of meta-analysis of outcomes for trainee- *versus* consultant-performed THA

Outcome (dichotomous)			95% CI			Heterogeneity			
	No studies	OR	Lower	Upper	p	x2	p	I^2	FE/RE
Revision rate	5	1.09	0.85	1.39	0.51	1.95	0.75	0	FE
Deep infection	5	1.49	0.93	2.41	0.1	0.61	0.96	0	FE
Dislocation	**6**	**1.3**	**0.96**	1.76	0.1	2.39	0.79	0	FE
			95% CI			Heterogeneity			
Outcome (continuous)	No studies	WMD	Lower	Upper	p	x2	p	I^2	FE/RE
Operation time	3	12.9	6.63	19.17	<0.01	9.1	0.01	78	RE
Length of stay	3	-0.03	-0.54	0.48	0.92	1.02	0.6	0	FE
HHS	3	-0.29	-2.53	1.95	0.8	6.92	0.03	71	RE
Supervised trainees *vs* consultants									
Outcome (dichotomous)			95% CI			Heterogeneity			
	No studies	OR	Lower	Upper	p	x2	p	I^2	FE/RE
Revision rate	4	1.19	0.9	1.56	0.22	1.66	0.65	0	FE
Dislocation rate	5	1.38	0.97	1.97	0.07	2.45	0.65	0	FE
Deep infection rate	4	1.64	0.94	2.86	0.08	1.02	0.8	0	FE
			95% CI			Heterogeneity			
Outcome (continuous)	No studies	WMD	Lower	Upper	p	x2	p	I^2	FE/RE
Operation time	2	9.48	6.33	12.62	< 0.01	0.53	0.47	0	FE

HHS = Harris Hip Score; OR = odds ratio; FE = fixed effects model; RE = random effects model; WMD = weighted mean difference.

Fig. 4). These results were associated with low heterogeneity ($I^2 = 0\%$).

Comparison of operation time

Three studies reported the mean operation time taken to complete THA for trainees *versus* consultants. Using a random effects model of meta-analysis, the consultant group was associated with lower mean operation times (WMD 12.9 minutes; 95% CI 6.63 to 19.17; p < 0.01, Fig. 5). There was a high degree of heterogeneity associated with this result ($I^2 = 78\%$).

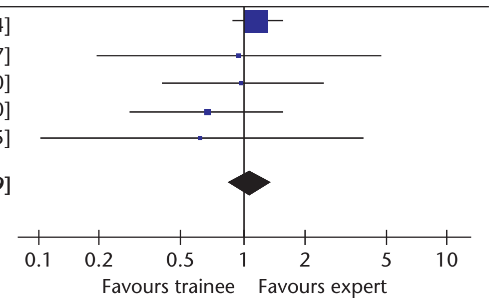
Comparison of length of stay

Three studies compared the results for length of stay between the two groups. There was no difference in length of stay for THA patients when trainees or consultants

(a)

Study or Subgroup	Trainee Events	Trainee Total	Expert Events	Expert Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Inglis 2012	62	4049	396	30344	76.2%	1.18 [0.90, 1.54]
Moran 2004	2	139	6	397	2.5%	0.95 [0.19, 4.77]
Palan 2009	7	528	13	973	7.5%	0.99 [0.39, 2.50]
Reidy 2016	7	286	21	584	11.2%	0.67 [0.28, 1.60]
Woolson 2007	2	119	3	111	2.5%	0.62 [0.10, 3.75]
Total (95% CI)		**5121**		**32409**	**100.0%**	**1.09 [0.85, 1.39]**
Total events	80		439			

Heterogeneity: Chi² = 1.95, df = 4 (P = 0.75); I² = 0%
Test for overall effect: Z = 0.66 (P = 0.51)



(b)

Study or Subgroup	Supervised trainee Events	Supervised trainee Total	Consultants Events	Consultants Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Inglis 2012	50	2982	396	30344	79.4%	1.29 [0.96, 1.73t]
Moran 2004	2	139	6	397	3.5%	0.95 [0.19, 4.77]
Reidy 2016	7	241	21	584	13.6%	0.80 [0.34, 1.91]
Woolson 2007	2	119	3	111	3.5%	0.62 [0.10, 3.75]
Total (95% CI)		**3481**		**31436**	**100.0%**	**1.19 [0.90, 1.56]**
Total events	61		426			

Heterogeneity: Chi² = 1.66, df = 3 (P = 0.65); I² = 0%
Test for overall effect: Z = 1.23 (P = 0.22)

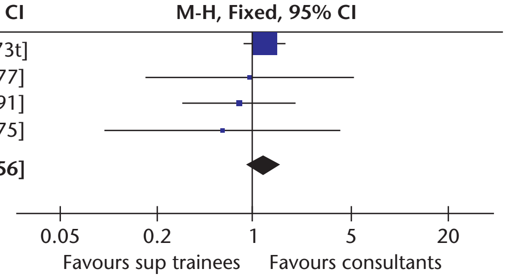


Fig. 2 Forest plot of meta-analysis for rate of revision surgery for: a) all trainees versus consultants; b) supervised trainees versus consultants.

Study or Subgroup	Trainee Events	Trainee Total	Expert Events	Expert Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Inglis 2012	13	4049	60	30344	57.0%	1.63 [0.89, 2.96]
Moran 2004	2	139	6	397	12.4%	0.95 [0.19, 4.77]
Reidy 2016	5	286	8	584	20.9%	1.28 [0.42, 3.95]
Weber 2017	2	240	4	768	7.6%	1.61 [0.29, 8.82]
Woolson 2007	1	119	0	111	2.1%	2.82 [0.11, 70.02]
Total (95% CI)		**4833**		**32204**	**100.0%**	**1.49 [0.93, 2.41]**
Total events	23		78			

Heterogeneity: Chi² = 0.61, df = 4 (P = 0.96); I² = 0%
Test for overall effect: Z = 1.64 (P = 0.10)

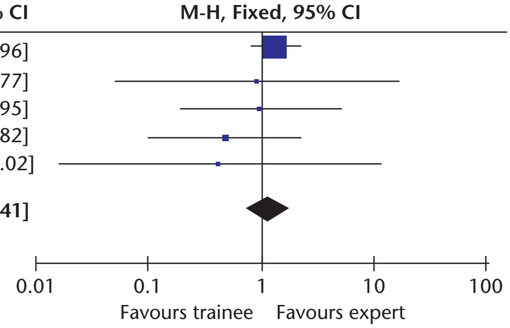


Fig. 3 Forest plot of meta-analysis of rate of deep infection following trainee- versus consultant-performed THA.

performed their operations (WMD -0.03; 95% CI -0.45 to 0.48; p = 0.92, Fig. 6). There was low heterogeneity associated with this result ($I^2 = 0\%$).

Comparison of Harris Hip Score at six months

The HHS at six months following THA was reported by three authors. No significant difference was observed between the two groups (WMD -0.29; 95% CI -2.53 to 1.95; p < 0.80, Fig. 7). There was high heterogeneity associated with this result ($I^2 = 71\%$).

Sensitivity analysis

Supervised trainees versus consultants

In the subgroup analysis for supervised trainees *versus* consultants, the trainee group was associated with a longer operation time (two studies, WMD 9.48; 95% CI

Study or Subgroup	Trainee Events	Trainee Total	Expert Events	Expert Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Inglis 2012	30	4049	147	30344	50.2%	1.53 [1.03, 2.27]
Moran 2004	2	139	6	397	2.5%	0.81 [0.17, 3.96]
Palan 2009	7	528	13	973	7.5%	1.11 [0.48, 2.55]
Reidy 2016	7	286	21	584	11.2%	1.08 [0.48, 2.46]
Weber 2017	2	119	3	111	2.5%	0.29 [0.02, 5.24]
Woolson 2007	2	119	3	111	2.5%	1.36 [0.50, 3.71]
Total (95% CI)		**5361**		**33177**	**100.0%**	**1.30 [0.96, 1.76]**
Total events	60		198			

Heterogeneity: $Chi^2 = 2.39$, df = 5 (P = 0.79); $I^2 = 0\%$

Test for overall effect: Z = 1.67 (P = 0.10)

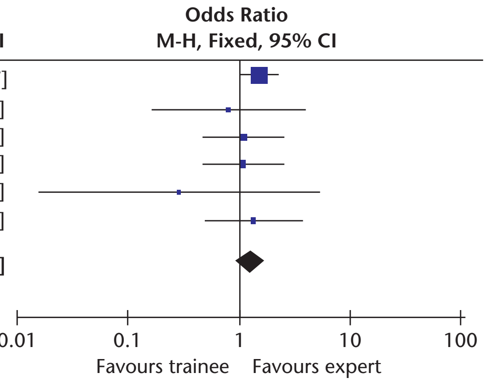


Fig. 4 Forest plot of meta-analysis of rate of dislocation for trainee- versus consultant-performed THA.

Study or Subgroup	Trainee Mean	Trainee SD	Trainee Total	Expert Mean	Expert SD	Expert Total	Weight	Mean Difference IV, Random, 95% CI
Palan 2009	104	50	528	85	56.5	973	32.2%	19.0 [13.45, 24.55]
Weber 2017	78.1	25.4	240	69.3	23.8	768	37.7%	8.80 [5.17, 12.43]
Woolson 2007	72.5	22	119	61	26.25	111	30.1%	11.50 [5.22, 17.78]
Total (95% CI)			**887**			**1852**	**100.0%**	**12.90 [6.63, 19.17]**

Heterogeneity: $TAU^2 = 23.72$; $Chi^2 = 9.10$, df = 2 (P = 0.01); $I^2 = 78\%$

Test for overall effect: Z = 4.03 (P = 0.0001)

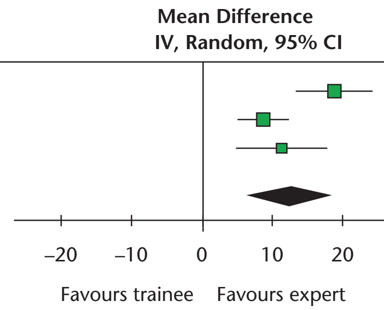


Fig. 5 Forest plot for meta-analysis of operation time for trainee- versus consultant-performed THA.

Study or Subgroup	Trainee Mean	Trainee SD	Trainee Total	Expert Mean	Expert SD	Expert Total	Weight	Mean Difference IV, Fixed, 95% CI
Palan 2009	11	27.7	528	9.8	10.2	973	4.3%	1.20 [–1.25, 3.65]
Weber 2017	8.13	5.65	286	8.15	11.5	584	20.0%	–0.02 [–1.16, 1.12]
Woolson 2007	5.1	1	119	61	3	111	75.6%	–0.10 [–0.69, 0.49]
Total (95% CI)			**933**			**1668**	**100.0%**	**–0.03 [–0.54, 0.48]**

Heterogeneity: $Chi^2 = 1.02$, df = 2 (P = 0.60); $I^2 = 0\%$

Test for overall effect: Z = 0.11 (P = 0.92)

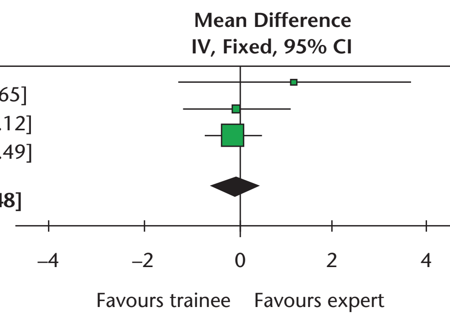


Fig. 6 Forest plot for meta-analysis of length of stay for trainee- versus consultant-performed THA.

6.33 to 12.62; $p < 0.01$; $I^2 = 0$, Table 6, Fig. 2b). There was no significant difference between the two groups for rate of revision, rate of dislocation or rate of deep infection.

Analysis of high-quality studies

In the sensitivity analysis of high-quality studies, there was no significant difference in rate of revision, rate of dislocation, rate of infection and length of stay between the two groups. Once again, trainees were associated with a longer operation time which was more pronounced than in the overall analysis (two studies; WMD 13.68; 95% CI 3.69 to 23.66; $p < 0.01$) (Table 7). Trainees were also associated with a less favourable HHS at six months (two studies; WMD -1.61; 95% CI -2.49 to -0.72; $p < 0.01$). In the high-quality analysis of supervised trainees *versus* consultants, there was no difference in rate of revision, rate of dislocation or rate of infection.

Qualitative analysis of functional outcome

Oxford Hip Score

Two studies assessed functional outcome using the Oxford Hip Score (OHS).[18,21] Inglis et al noted a significantly superior OHS for consultants compared with supervised trainees (40.7 *vs* 38.95; $p < 0.001$) (Table 8) and unsupervised trainees (38.27; $p < 0.001$). There was no significant difference in OHS between supervised and unsupervised groups. Palan et al measured mean change in OHS pre- and post-operatively for trainee and

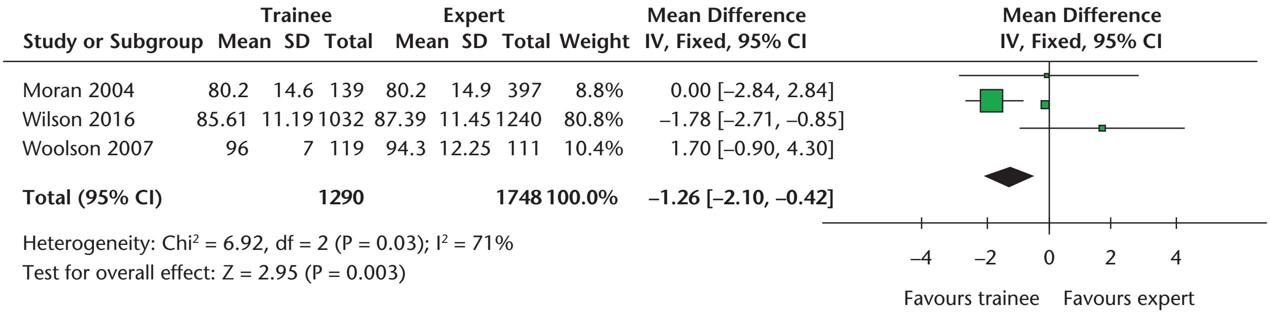


Fig. 7 Forest plot for meta-analysis of Harris Hip Score (HHS) for trainee- versus consultant-performed THA.

Table 7. Results of meta-analysis of outcomes for trainee- *versus* consultant-performed THA – sensitivity analysis for high-quality studies

Outcome (dichotomous)			95% CI			Heterogeneity			
	No studies	OR	Lower	Upper	p	x2	p	I²	FE/RE
Revision rate	3	0.82	0.46	1.47	0.5	0.4	0.82	0	FE
Deep infection	3	1.24	0.55	2.79	0.6	0.2	0.91	0	FE
Dislocation	4	0.98	0.58	1.67	0.94	0.88	0.83	0	FE
			95% CI			Heterogeneity			
Outcome (continuous)	**No studies**	**WMD**	**Lower**	**Upper**	**p**	**x2**	**p**	**I²**	**FE/RE**
Operation time	2	13.68	3.69	23.66	0.007	9.09	0.003	89	RE
Length of stay	2	0.2	-0.384	1.23	0.71	0.78	0.38	0	FE
HHS	2	-1.61	-2.49	-0.72	<**0.01**	1.37	0.24	27	FE
Supervised trainees *vs* consultants									
Outcome (dichotomous)			**95% CI**			**Heterogeneity**			
	No studies	**OR**	**Lower**	**Upper**	**p**	**x2**	**p**	**I²**	**FE/RE**
Revision rate	2	0.83	0.39	1.79	0.64	0.03	0.85	0	FE
Dislocation rate	3	0.93	0.47	1.9	0.84	0.88	0.64	0	FE
Deep infection rate	2	1.09	0.34	3.43	0.89	0.33	0.57	0	FE

HHS = Harris Hip Score; OR = odds ratio; FE = fixed effects model; RE = random effects model; WMD = weighted mean difference.

consultant groups (Table 8). No significant difference in change of OHS was noted between trainees and consultants at three-month follow-up as well as at the one-, two-, three-, four- and five-year follow-ups. The consultant group was noted to have a higher post-operative OHS at five years compared with trainees (40.5 *vs* 39.2; p = 0.02), but the consultant group had a higher pre-operative OHS. When comparing senior and junior trainee groups, Palan reported no difference in change in OHS between the two groups at three months, two years and three years, but a significantly better change in OHS for senior trainees at one, four and five years. Meta-analysis of long-term functional outcome was not performed due to variation in type of data reported (i.e. change in OHS *versus* OHS) and variation of follow-up intervals between studies.

Harris Hip Score

Three studies compared HHS between consultants and trainees at various follow-up intervals.[16,17,19] Two of these studies were included in the meta-analysis of HHS scores at six months.[16,17] Reidy et al found no significant difference between trainees and consultants both pre-operatively and at one-, three-, five-, seven- and ten-year follow-up. There was a significant loss to follow-up in the analysis at seven and ten years. Moran et al reported no significant differences in HHS at 18 months between the two groups (84.6 *vs* 86.4).

Other outcomes

Weber et al reported no difference in WOMAC score and EQ-50 scores between trainee and consultants at one-year follow-up.[15] Moran et al noted a significant difference in cup anteversion between trainees and consultants.[16] Trainee-sited cups were in 6.1° anteversion compared with 11.4° for consultants, when measured using Pradhan's technique (p < 0.001). Other outcomes were no different between the two groups.

Table 8. Functional outcomes

References	Oxford Hip Score	Harris Hip Score	Other scores
Inglis	Significantly superior OHS at 6-month follow-up for consultants (40.7) *vs* supervised trainees (38.95; p < 0.001) and unsupervised trainees (38.27; p = 0.001). No significant difference in OHS between supervised and unsupervised groups	N/A	
Moran	N/A	No significant difference in HHS at 6 months between consultant (80.2) *vs* trainees (80.2), no significant difference in HHS at 18 months between consultant (84.6) and trainees (85.4)	
Palan	No significant difference in change of OHS between two groups at 3 months, 1, 2, 3, 4 and 5 years. Superior post-operative OHS scores at 5 years in consultant group compared with trainee group (40.5 *vs* 39.2; p = 0.02); however, consultants had higher OHS pre-operatively. Mean change in OHS at 5-year follow-up for senior registrars was 25.2 compared with 21.8; p = 0.001	N/A	
Reidy	N/A	No significant difference in HHS pre-operatively and up to 10 years post-operatively between consultants, junior and senior trainees. Significant decrease in number of patients at 7- and 10-year follow-up (n = 136 and 277, respectively)	
Weber	N/A	N/A	No difference in WOMAC and EQ-5D scores between trainee or senior surgeon operators at 1 year
Wilson	N/A	N/A	
Woolson	N/A	No significant difference in HHS at 6 months between consultants (94.3) and trainees (96)	

Discussion

The present study has demonstrated no difference in the rate of revision surgery, the rate of deep infection and the rate of dislocation when trainees perform THA compared with consultant surgeons. We can infer from this that trainees are safe to operate in selected cases under supervision from consultants. These results are reassuring for both patients and trainers. Demand for THA is forecast to rise significantly over the next decade.[1] Orthopaedic trainees must be sufficiently competent to operate independently as consultants to provide a safe service for patients and must become competent in a variety of technical skills and procedures. Changes to training over the last decade include the increasing use of simulation, and in some settings, a move towards a competency-based rather than time-based training model.[22-24] There is no real substitute for the opportunity to perform operations in a real-life setting. The findings of this paper demonstrate that the 'apprenticeship model' of surgical training is safe and should be maintained.

This study has shown that trainees take significantly longer to perform THA compared with consultants. While some service providers may have reservations about efficiency, the data show that training need not hamper efficiency to a large extent. The difference of 13 minutes represents the learning curve of the trainee, and while not insignificant, is a relatively short time and an acceptable 'cost' of training. There are estimates in the literature regarding the added cost associated with trainee-performed surgery.[25] Weber et al estimated an additional $33 000 for 230 THAs performed by trainees, which equates to $140 per case.[15] Clearly, this is a crude estimate and is likely to vary significantly; however, it does provide a rough indication of the low cost. A recent *BMJ* paper, evaluating the cost of operating theatre time per hour, estimated this as approximately £1200 per hour, equating to £240 for 13 minutes.[26]

Interestingly, our subgroup analysis for supervised trainees *versus* consultants showed no significant difference between the two groups, compared with the overall analysis. This is likely attributable to a faster intra-operative decision-making process with a consultant present. The unsupervised trainee may be slower to deal with unexpected steps whereas consultant presence, even when a trainee is performing the procedure, keeps the operation moving.

With regards to our secondary outcomes, we found no difference in rates of deep infection. In fact, overall rates of infection were low in both groups, in the range of 0.9% to 1.7% for the trainee group and 0.2% to 1.7% for the consultant group; infection rates across all studies were within limits accepted in the literature.[27] It is possible that rate is underreported due to the retrospective nature of the data; however, the key finding of no difference between trainees and consultants is reassuring.

In terms of functional outcome, there was no difference in HHS between consultants and trainees at six-month follow-up in the overall analysis; however, in the analysis of high-quality studies, consultants were associated with small but significantly improved HHS compared with trainees. While it is statistically significant, it is unlikely to be clinically significant, especially given the inherent case selection bias associated with predominantly retrospective data, e.g. Moran et al demonstrated that trainees were operating on significantly older patients. A recent retrospective analysis of 8158 THAs by Jolback et al found no association between surgeons' experience and EQ-5D (Euroqol group) index, EQ-VAS (Euroqol group visual analogue scale) and pain VAS (visual analogue scale) one year after surgery. The authors did, however, find lower VAS scores one year after THA for trainees when compared with surgeons who had > 15 years' experience.

Several studies within the orthopaedic literature, which were not suitable for inclusion in our analysis, have examined the impact of trainee involvement in arthroplasty and scoliosis surgery. These studies have also found no increase in adverse event rates associated with operations involving or being performed by trainees. Schoenfield et al reviewed data relating to total joint arthroplasties (hip and knee) with and without trainee involvement. The authors found a significantly higher rate of one or more complications and major systemic complications for operations involving a trainee compared with ones with no involvement.[5] However, the cohorts in each group were subject to unknown case-mix and unknown levels of resident involvement. Given these added variables, which were not adjusted for, it is unreasonable to attribute this difference in outcome purely to trainees. To mitigate this added source of bias, our analysis only included studies where trainees were performing the THA (i.e. as primary operator), as opposed to merely being involved in the procedure. This makes our findings more specific to trainee outcomes.

This study was subject to a number of limitations, the most important being selection bias due to the use of non-randomized data. Consultants would therefore be more likely than trainees to operate on more challenging cases, thus subjecting both groups to a different case-mix. Adjusting for variations in case-mix between the groups was not possible due to lack of reported data and a low number of studies precluding a meta-regression model of analysis.

An additional limitation is the uneven size of the consultant and trainee groups in the overall analysis. However, when considering the high-quality sensitivity analysis, the groups were more balanced with 36.0% (2225/6187) in the trainee group and 64.0% (3962/6187) in the consultant group. The fact that few differences were observed in the results of the sensitivity analysis compared with the overall analysis suggests that this unevenness had a limited effect.

The definition of supervision varies widely across all studies and in many it is not explicitly described. This reflects the nature of real-life training where supervision can take many forms, depending on the experience and seniority of the trainee as well as the relationship between trainer and trainee. Supervision is a spectrum rather than a binary value. The arbitrary division of trainees into junior and senior in some studies was based on heterogenous definitions. Some studies based this on year of training/residency, which is a reasonable method.[18,19] This may not always reflect ability and levels of confidence, e.g. a year 1 and a year 3 resident would both be classified as junior residents but there is likely to be a difference in ability.

The incidence of complications such as revision and infection rate are subject to the length of follow-up. The studies included in our analysis had a mean follow-up of 42 months for the primary outcome. Clearly, longer follow-up intervals may yield a higher number of revision surgeries.

It is important to note that studies such as the ones included will always be limited in terms of quality given the hypothesis being tested. Randomized data are unlikely to become available for this type of comparison and this analysis summarizes the best available evidence. There is, however, a lack of data relating to long-term outcome for trainee-performed THA and these data would certainly be a valuable addition to the literature.

Conclusion

The present meta-analysis has shown that, in selected cases, trainees are safe to perform THA under supervision, with no adverse impact on patient outcomes or short-term functional outcome. This provides reassurance to trainees and their trainers as well as patients. In addition, the lack of difference in length of stay and acceptable increase in operation time should be viewed favourably by managers, service providers, trainers and, most importantly, patients.

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ICMJE CONFLICT OF INTEREST STATEMENT

None declared.

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