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REVIEW

Minimally invasive versus conventional exposure for total hip arthroplasty: a systematic review and meta-analysis of clinical and radiological outcomes

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Abstract Over the past decade, minimally invasive surgery has gained popularity as a means of optimising early postoperative rehabilitation and increasing patient satisfaction and cosmesis following total hip arthroplasty (THA). However, this surgical exposure has also been associated with increased risk of iatrogenic nerve injury and implant mal-positioning due to limited visibility compared to conventionally larger surgical incisions. The purpose of this meta-analysis was to compare the outcomes of these two surgical exposures. A systematic review of the published and unpublished literature was conducted to include all randomised and non-randomised controlled trials comparing the clinical and radiological outcomes of minimally invasive and conventional THA procedures. In total, 28 studies met the eligibility criteria and included 2,849 hips, i.e. 1,428 minimally invasive compared to 1,421 conventional THAs. The meta-analysis of the current evidence base showed that minimally invasive THA is associated with a significantly increased risk of transient lateral femoral cutaneous nerve palsy (p=0.006) with no significantly better outcome.

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Introduction

Total hip arthroplasty (THA) is the treatment of choice for degenerative changes of the hip joint. The traditional and still most commonly used approaches for primary THA are the posterior approach and direct lateral approach [1–3]. Whilst the recovery and early postoperative outcomes of this procedure have improved over the last 20 years, there remains great interest in accelerated rehabilitation and improving functional outcomes whilst reducing the surgical scar following a THA.

The minimally invasive surgical (MIS) exposure in THA surgery was developed to reduce postoperative bleeding, speed patient recovery and improve the early clinical results [1]. Minimally invasive THA has been defined as an incision length of 10–12 cm or less either with a single or double incision approach [4–8]. Surgeons have suggested that the smaller skin incision, with reduced soft tissue trauma to muscles, tendons and other soft tissues surrounding the hip should result in less postoperative pain, enhance the patient experience and reduce the length of hospital stay [9–12].

Detractors of MIS have suggested that the approach reduces the operative visualisation thus predisposing patients to implant mal-positioning with an increased risk of dislocation, implant loosening and early failure, in addition to an increased risk of neurovascular complications and excessive skin trauma [13, 14].

A previous meta-analysis suggested that there was little difference in the clinical or radiological outcomes following MIS compared to standard exposure THA [15]. However, this study only included randomised and quasi-randomised controlled trials. The purpose of this systematic review was to appraise the entire evidence base to compare the clinical and radiological outcomes of patients who have undergone a traditional exposure to a MIS exposure for THA. The primary aim of the systematic review was to determine whether MIS is superior to a conventional exposure with reference to short- and long-term outcomes.

Materials and methods

Search strategy

All PRISMA compliant searches were performed by TS and CH. The primary search was of published literature using the electronic databases AMED (1985 to April 2010), British Nursing Index (1985 to April 2010), CINHAL (1982 to April 2010), EMBASE (1974 to April 2010) and MEDLINE (1950 to April 2010) using the Ovid search platform. In addition, Scopus, Biomed Central, Zetoc and the Cochrane Library databases were searched. The broad MeSH terms and Boolean operators ("minimally invasive") AND ("hip") AND ("replacement" OR "arthroplasty") were adopted for each database search.

Secondary searches of the unpublished (grey) literature were conducted by searching the electronic databases Open SIGLE (System for Information on Grey Literature in Europe), the WHO International Clinical Trials Registry Platform, Current Controlled Trials, UKCRN Portfolio Database, National Technical Information Service and the UK National Research Register Archive from their inception to April 1, 2010. Conference proceedings were also searched from the British Orthopaedic Association Annual Congress, European Federation of National Associations of Orthopaedics and Traumatology (EFORT) and the British Hip Society to April 2010.

The reference lists from all full text papers included in the review were scrutinised to identify any initially omitted studies. Finally, the corresponding author from each included study was contacted to identify any further studies not previously identified.

Eligibility criteria

All randomised controlled trials (RCTs) and non-randomised controlled trials (nRCT) comparing the clinical and/or radiological outcomes of THA using a standard exposure to a MIS exposure were included. All trials comparing the exposure method, irrespective of whether computer navigation systems were employed in the MIS surgical arm were included. All trials were included irrespective of their publication status, language, sample size, subject age, indication for surgery, duration of follow-up or surgical approach (i.e. lateral or posterior) undertaken. We excluded all cadaver or animal studies, and those studies assessing exposure method with hip resurfacing or hemi-arthroplasty. We also excluded all trials which used multiple incisions for their MIS rather than a single surgical exposure.

Study selection

The title and abstract for each identified citation were independently screened by two reviewers (TS, CH) in relation to the eligibility criteria. Full texts were ordered for those studies which appeared to satisfy these criteria and reviewed independently to determine final inclusion.

Data extraction

Data from the full text reports were extracted by one reviewer (TS) using a standardised data extraction form, and verified by a second reviewer (VB). The data extracted included: sample size, study design, subject age, gender, THA prosthesis, number of surgeons operating, surgical technique, incision approach, clinical, radiological and complication rate results and follow-up period. The corresponding authors from each included study were contacted to obtain any missing data if required.

Outcome

The primary outcome for this study was Harris hip score (HHS). Secondary clinical outcomes included: surgical duration, blood loss, pain, requirement for blood transfusion, length of hospital stay, Oxford hip score (OHS) and Western Ontario and McMaster Universities osteoarthritis index score (WOMAC). Radiological secondary outcomes included: cup inclination angle, stem alignment (varus/valgus) angle, leg length discrepancy, femoral offset, incidence of cup positioning (35–55° valgus) and the incidence of stem positioning (0–5° valgus). Complications included: the incidence of heterotopic ossification, deep and superficial infection, fracture, deep vein thrombosis (DVT), dislocation, haematoma formation, requirement for revision surgery, component loosening, wound complications and the incidence of iatrogenic nerve palsy.

Quality assessment

Study methodological quality was assessed according to the PEDro critical appraisal tool. This 11-item critical appraisal tool is designed to evaluate comparability between the groups, method of randomisation, blinding and statistical analysis of RCTs. This instrument has previously demonstrated reliability and validity [16, 17].

Data synthesis and analysis

All meta-analyses were performed with the Review Manager software (RevMan Version 5.0; Nordic Cochrane Centre, Copenhagen, Denmark) using the Mantel-Haenszel method [18]. Publication bias was assessed using a funnel plot of the most frequently reported outcome.

Meta-analysis was performed when no substantial heterogeneity in study methodology was observed. Specific statistical heterogeneity was evaluated through Chi^2 and I^2 statistical tests. When Chi^2 was $p<0.05$, and $I^2<20\%$ indicating low statistical heterogeneity [19], a fixed effect model was used. A random effect model was adopted when Chi^2 was $p>0.05$, and $I^2>20\%$.

Binary data was analysed using risk ratios (RR) with 95% confidence intervals (CI). Continuous data was assessed with mean differences (MD) or, where different scales or tools are used to measure the same outcome, standardised mean differences with 95% CI. A probability of $p<0.05$ was considered as statistically significant.

Sub-group analyses were conducted to assess outcomes with and without the assistance of computer navigation for MIS compared to traditional exposure. However, since only one study used computer navigation-assisted surgery for a small proportion of their patients, we did not consider it necessary to undertake a sub-group analysis of this variable.

Results

Search results

A total of 534 abstracts and titles were reviewed. Of these 28 satisfied the eligibility criteria and were included in the review (Fig. 1). This included 16 nRCTs and 12 RCTs. Two studies were identified reporting the same cohort. In this instance we included both papers but only analysed the data for each outcome measure once. One study presented the results of two separate surgical approaches using MIS and conventional exposures; both were included in separate analyses [20].

The funnel plot diagram of surgical duration indicated limited evidence of small study exclusion and publication bias with a slightly asymmetrical plot with few studies plotted on the right base of the funnel (Fig. 2).

Quality assessment

The results of the PEDro review are presented in Table 1. This indicated that there was considerable variability in the evidence base. Whilst the majority of papers defined their cohorts, as previously stated, only 12 RCTs were identified. Of these, only four concealed the randomisation procedure adequately. A power calculation was used to base the sample size in six studies. Furthermore, only five studies presented both outcome measure and demographic characteristics to allow a full assessment of baseline comparability before the trial began. Only three trials attempted to blind subjects to groups allocation. Whilst surgeon blinding would have been inappropriate in this study design, 16 studies did not blind their assessors to patient group. Ten studies were able to report the outcomes of a minimum of 85% of their starting cohorts; although 13 trials described analysing results through intention-to-treat principles. All studies appropriately used inferential statistics to compare the findings between their experimental cohorts, and all but eight presented both mean and standard deviation or range values to provide an idea of point and variance data from their dataset.

Cohort characteristics

The demographic characteristics of each study cohort are presented in Table 2. The dataset included 2,825 patients who underwent 2,849 THA procedures. This included 1,428 MIS, with a mean age of 61.8 (standard deviation [SD] 3.9) years including 609 males and 602 females; six studies did not document the gender of their cohort. This group was compared to 1,421 conventional exposure THAs with a mean age of 61.5 (SD 4.9) years, consisting of 610 males and 610 females; six papers did not state the gender of their cohorts.

The most commonly used THA MIS approach was the mini-posterior performed in 12 studies. The most commonly adopted conventional THA approach was the standard posterior approach used in seven studies. Computer navigation surgery was performed in some cases in one study [21]. Follow-up period ranged from five days [22] to five years [9, 23].

Primary outcome analysis

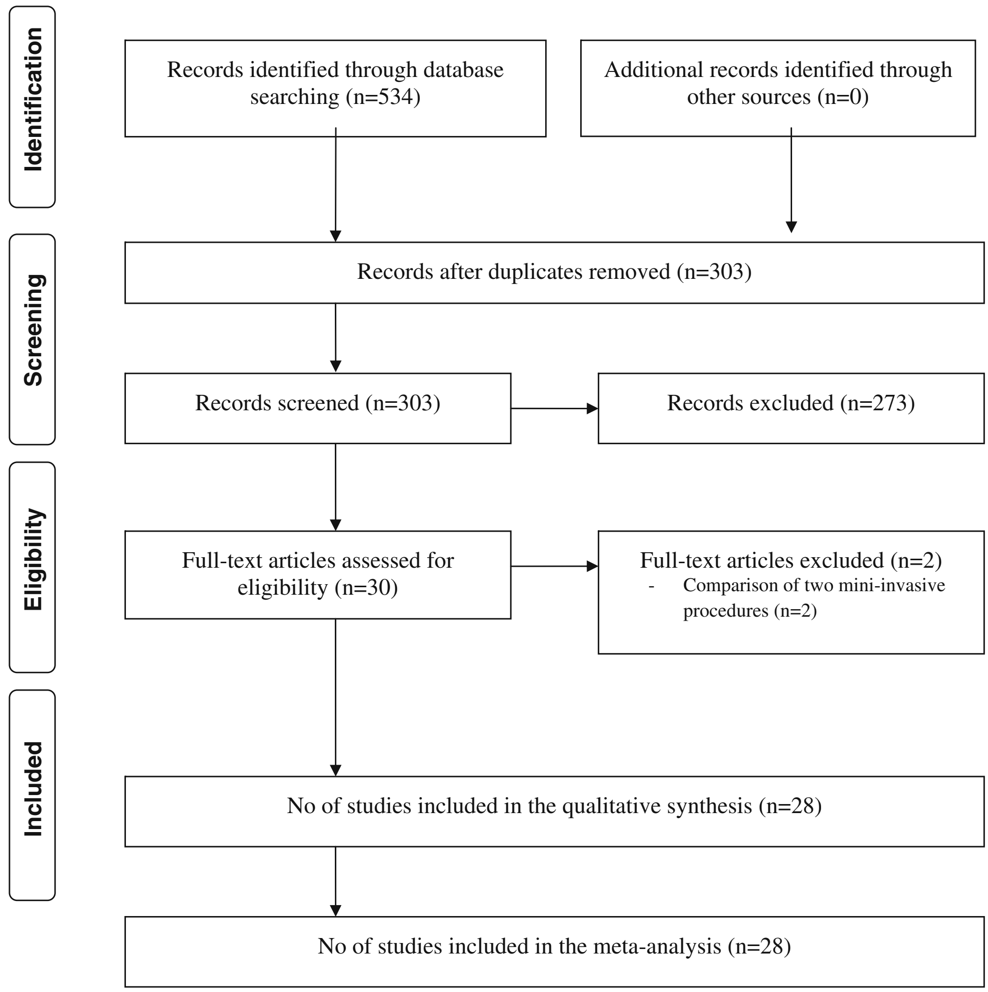
There was no significant difference in HHS recorded for the MIS compared to the conventional exposure THA (MD 1.49; 95% CI −0.08, 3.06; $p=0.06$; Fig. 3). A difference of less than 2 points would also not be considered a clinically significant difference [24, 25].

Secondary outcome analysis

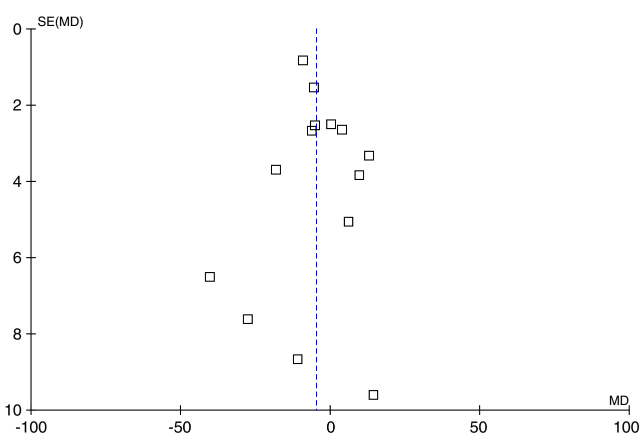
Clinical outcomes

As anticipated there was a significantly smaller surgical incision length following MIS compared to conventional THA with a mean difference of 8.0 cm ($p<0.0001$; Table 3). There was however no statistically significant difference in

Fig. 1 PRISMA chart



surgical duration between MIS and conventional exposure (MD 4.65 minutes; 95% CI −9.45, 0.15; p=0.06). Whilst there was statistically less perioperative blood loss in the MIS group compared to conventional THA (p<0.001; Table 3), there was no statistically significant difference between the groups in respect to drained postoperative blood loss, total blood loss or requirement for blood transfusion (p>0.05; Table 3).



SE (MD) – Standard error (mean difference)

Fig. 2 Funnel plot to assess publication for the most frequently reported outcome—surgical duration. *SE (MD)* standard error (mean difference)

There was no statistically significant difference between the exposure method in respect to WOMAC score (p=0.13) or OHS (p=0.29). Although patients who underwent MIS reported lower pain scores on visual analogue scale (VAS) assessment (MD=0.58; p=0.02) and a shorter hospital length of stay (MD=0.59; p=0.01), these differences were not clinically substantial between the groups.

Radiological outcomes

As Table 4 demonstrates, there was no statistically significant difference between the MIS or conventional THA exposure methods with respect to any radiological measurement recorded in this meta-analysis.

Complications

There were no statistically significant differences between the exposure methods during THA for complications such

Table 1 PEDro critical appraisal score

Study	PEDro criteria											Total
	1	2	3	4	5	6	7	8	9	10	11	
Yang et al. [49]	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	9
Lawlor et al. [50]	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y	9
Ogonda et al. [35]	Y	Y	Y	Y	Y	N	Y	N	N	Y	Y	8
Goosen et al. [44]	Y	Y	N	Y	N	N	Y	Y	N	Y	Y	8
Chimento et al. [6]	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	8
Kim [51]	Y	Y	N	Y	N	N	Y	Y	N	Y	Y	7
Dorr et al. [21]	Y	Y	N	Y	N	N	Y	N	Y	Y	Y	7
Bennett et al. [22]	N	Y	Y	Y	N	N	Y	N	Y	Y	N	6
Rittmeister and Peters [52]	Y	N	N	Y	N	N	N	N	Y	Y	Y	5
Leuchte et al. [53]	Y	N	N	N	N	N	N	N	Y	Y	Y	5
Kubeš et al. [54]	Y	N	N	Y	N	N	N	Y	N	Y	Y	5
Chen et al. [26]	Y	N	N	N	N	N	N	Y	N	Y	Y	5
Szendrõi et al. [55]	Y	N	N	Y	N	N	Y	N	N	Y	Y	5
Shitama et al. [20]	Y	Y	N	Y	N	N	N	N	N	Y	Y	5
Sculco et al. [23]-2nd	N	Y	N	Y	N	N	N	Y	N	Y	N	4
Speranza et al. [32]	Y	Y	N	Y	N	N	N	N	N	Y	N	4
Vicente et al. [1]	N	N	N	Y	N	N	N	N	Y	Y	Y	4
Wenz et al. [47]	Y	N	N	N	N	N	N	N	Y	Y	Y	4
Pospischill et al. [56]	Y	Y	N	N	N	N	N	N	N	Y	Y	4
Mow et al. [48]	N	N	N	N	N	N	Y	Y	Y	Y	N	4
Laffosse et al. [45]	N	N	N	Y	N	N	N	N	Y	Y	Y	4
Laffosse et al. [57]	Y	N	N	N	N	N	N	N	Y	Y	Y	4
Howell et al. [38]	Y	N	N	N	N	N	N	N	Y	Y	Y	4
Wohlrab et al. [58]	Y	N	N	Y	N	N	N	N	N	Y	N	3
Woolson et al. [30]	Y	N	N	N	N	N	Y	N	N	Y	N	3
Wright et al. [9]	N	N	N	N	N	N	N	Y	N	Y	Y	3
Sculco et al. [23]	N	N	N	Y	N	N	N	Y	N	Y	N	3
Pflüger et al. [59]	N	N	N	N	N	N	N	N	Y	Y	N	2

Y Yes, *N* No

1. Eligibility criteria
2. Random allocation
3. Concealed allocation
4. Baseline comparability
5. Blind subject
6. Blind clinician
7. Blind assessor
8. Adequate follow-up
9. Intention-to-treat analysis
10. Between-group analysis
11. Point estimates and variability

as infection rates, intra- or postoperative fracture, dislocation rate, DVT, haematoma formation, wound complications or component loosening. There was however a statically significant difference in respect to iatrogenic nerve palsy with a five times greater rate of nerve palsy following MIS surgery compared to conventional THA ($p<0.0001$; Fig. 4). When assessed individually, the risk of transient lateral femoral cutaneous nerve palsy was significantly higher following MIS (RR=16.2; $p=0.006$; Fig. 5); however, this finding was weighted by a high proportion of cases reported in a cohort study by Chen et al. [26]. There was no statistically significant difference between the groups with respect to the incidence of sciatic nerve palsy ($p=0.11$; Table 5).

Discussion

The findings of this review of the current evidence base suggest that MIS THA results in a significantly increased risk of lateral femoral cutaneous nerve palsy. There was no clinically significant reduction in total blood loss or hip scores at final follow-up with no difference in radiological outcomes at final review compared to a conventional approach. Whilst hospital stay and pain scores were lower in the MIS group, this was not a clinically significant difference.

The PEDro appraisal identified a number of methodological limitations to the current evidence base. These were largely cited as poor concealment of randomisation, permitting selection and allocation bias, not blinding patients and assessors to their surgical exposure, allowing further expectation and assessor bias, and not recruiting sample sizes based on an appropriate power calculation, allowing the potential for type II statistical error from impacting on the findings of these clinical studies [27, 28]. Accordingly, whilst the findings of this meta-analysis should be considered as appropriate, based on the best available literature, these methodological shortcomings should be considered when interpreting the findings.

Table 2 Cohort characteristics

Study	Design	Sample Size		THA		Mean age (years)		Gender (m/f)		Approach	Follow-up
		Pts	THAs	MIS	Conv	MIS	Conv	MIS	Conv		
Bennett et al. [22]	RCT	95	95	43	52	66.1	64.6	18/25	28/24	MIS-mini-posterior (≤10 cm) Conv-std posterior (16 cm)	5 days
Chen et al. [26]	nRCT	166	166	83	83	53.5	55	46/37	41/42	MIS-mini anterolateral Conv-std anterolateral	2 years
Chimento et al. [6]	RCT	60	60	28	32	67.2	65.6	16/12	13/19	MIS-mini posterolateral Conv-std posterolateral	2 years
Dorr et al. [21]	RCT	60	60	30	30	70.3	63.9	17/13	14/16	MIS-Mini-posterior with navigation in 27/30 Conv-Posterior	6 months
Goosen et al. [44]	RCT	120	120	60	60	60	62	30/30	29/31	MIS-mini-anterolateral/mini posterior Conv-std anterolateral/ posterior	1 year
Howell et al. [38]	nRCT	107	107	50	57	59.8	62.3	34/16	27/30	MIS-mini-anterolateral Conv-std anterolateral	N/S
Kim [51]	RCT	140	140	70	70	55.6	55.6	53/17	53/17	MIS-mini-posterolateral Conv-std posterolateral	26.4 months
Kubeš et al. [54]	nRCT	80	80	40	40	67	66.1	14/26	19/26	MIS-mini anterolateral Conv-std anterolateral	2 years
Laffosse et al. [45]	nRCT	100	100	42	58	57.4	59.7	24/18	33/25	MIS-mini-anterolateral Conv-std posterior	6 months
Laffosse et al. [57]	nRCT	110	116	58	58	55	59.7	35/23	33/25	MIS-mini-posterior Conv-std posterolateral	6 months
Lawlor et al. [50]	RCT	219	219	109	110	67.4	65.9	49/60	58/52	MIS-mini-posterior ≤10 cm Conv-std posterior 16 cm	6 weeks
Leuchte et al. [53]	nRCT	32	32	16	16	59.7	62.6	N/S	N/S	MIS-mini anterolateral Conv-std lateral	28 weeks
Mow et al. [48]	nRCT	32	34	20	14	59	63	13/6	7/6	MIS-mini-posterior Conv-direct lateral	24 months
Ogonda et al. [35]	RCT	219	219	109	110	67.4	65.9	49/60	58/52	MIS-mini-posterior ≤10 cm Conv-std posterior 16 cm	6 weeks
Pflüger et al. [59]	nRCT	100	100	50	50	N/S	N/S	N/S	N/S	MIS-mini anterolateral Conv-std anterolateral	N/S
Pospischill et al. [56]	RCT	40	40	20	20	61.9	60.6	8/12	12/8	MIS-mini-anterolateral approach Conv-std lateral approach	12 weeks
Rittmeister and Peters [52]	nRCT	152	152	76	76	60	65	23/53	23/53	MIS-mini-posterior Conv-anterolateral	4 days
Sculco et al. [23]	nRCT	84	84	42	42	67.2	65.6	12/16	19/13	MIS-mini-anterolateral Conv-N/S	5 years
Sculco et al. [23] - 2nd study	RCT	60	60	28	32	N/S	N/S	N/S	N/S	MIS-mini-anterolateral (8 cm) Conv-N/S (15 cm incision)	Min 2 years
Shitama et al. PL [20]	RCT	39	39	19	20	58.3	61.3	N/S	N/S	MIS-mini-posterolateral Conv-posterolateral	6 months
Shitama et al. TL [20]	RCT	23	23	15	8	61.7	53.4	N/S	N/S	MIS-mini-translateral Conv-translateral	6 months
Speranza et al. [30]	RCT	100	100	50	50	65	66.2	20/26	23/21	MIS-mini-lateral (≤8 cm) Conv-std lateral (12-14 cm)	6 months
Szemdrõi et al. [55]	nRCT	59	59	38	21	64	57	N/S	N/S	MIS-mini-lateral (<10 cm) Conv-std lateral (>14 cm)	3 months
Vicente et al. [1]	nRCT	76	76	34	42	50	57	21/13	26/16	MIS-mini posterior <11 cm	6 months

Table 2 (continued)

Study	Design	Sample Size		THA		Mean age (years)		Gender (m/f)		Approach	Follow-up
		Pts	THAs	MIS	Conv	MIS	Conv	MIS	Conv		
										Conv-direct lateral	
Wenz et al. [47]	nRCT	173	189	124	65	63	65	60/64	22/43	MIS-mini-posterior Conv-direct lateral	N/S
Wohlrab et al. [58]	nRCT	50	50	27	23	58.8	61.9	11/26	11/12	MIS-mini posterior Conv-std lateral	3 months
Woolson et al. [30]	nRCT	135	135	50	85	60	63	29/21	31/54	MIS-mini-posterior Conv-posterior	Min 6 months
Wright et al. [9]	nRCT	84	84	42	42	65.0	64.2	N/S	N/S	MIS-mini-posterolateral Conv-posterolateral	5 years
Yang et al. [49]	RCT	110	110	55	55	59	56	26/29	30/25	MIS-mini-anterolateral Conv-posterolateral	3 years

THA total hip arthroplasty, *Conv* conventional surgery, *f* females, *m* males, *Min* minimum, *MIS* minimally invasive surgery, *nRCT* non-randomised controlled trial, *N/S* not stated, *PL* posterolateral approach, *RCT* randomised controlled trial, *TL* translateral approach

A major finding reported by the overall meta-analysis was the significantly greater risk of iatrogenic nerve injury during MIS compared to conventional procedures. One suggestion for this is related to retractor position. Yoon et al. [29] suggested that femoral nerve palsy, for instance, may be associated with retractor position [29]. The anterior retractor should be underneath the rectus femoris muscle to prevent this. Similarly, reduced operative visibility may increase the potential for nerve injury due to the added difficulty in identifying nerves during dissection.

Although not included in this meta-analysis, Woolson et al. [30] reported acetabular and femoral prostheses were

Study or Subgroup	MIS Mean	MIS SD	MIS Total	Conventional Mean	Conventional SD	Conventional Total	Weight	Mean Difference IV, Random, 95% CI
Chimento et al 2005	70.3	10.7	28	70	8.5	32	8.4%	0.30 [-4.64, 5.24]
Dorr et al 2007	99.69	24.57	30	110.67	40.61	30	4.3%	-10.98 [-27.96, 6.00]
Howell et al 2004	97	19	50	84	15	57	7.9%	13.00 [6.45, 19.55]
Kim 2006	52	4.8	70	61	5.1	70	9.2%	-9.00 [-10.64, -7.36]
Kubes et al 2009	70.1	9.96	40	75.3	12.6	40	8.4%	-5.20 [-10.18, -0.22]
Laffosse et al 2006	82.4	19	42	72.6	19	58	7.5%	9.80 [2.25, 17.35]
Laffosse et al 2007	74.4	0	58	72.6	0	58		Not estimable
Ogonda et al 2005	60.3	9.2	109	65.9	13.2	110	8.9%	-5.60 [-8.61, -2.59]
Pfluger et al 2007	58	0	50	56	0	50		Not estimable
Rittmeister 2006	80	0	76	80	0	76		Not estimable
Sculco et al (2004) 2nd	0	0	28	0	0	32		Not estimable
Sculco et al 2004	71	0	42	77	0	42		Not estimable
Shitama et al 2009 PL	86.8	14.6	19	80.5	17	20	6.6%	6.30 [-3.63, 16.23]
Shitama et al 2009 TL	104.3	23.5	15	90	21	8	3.8%	14.30 [-4.49, 33.09]
Speranza et al 2007	101	0	50	117	0	50		Not estimable
Szendroi et al 2006	84	16	38	102	12	21	7.7%	-18.00 [-25.23, -10.77]
Vicente et al 2008	97.5	26	34	125	40	42	4.9%	-27.50 [-42.42, -12.58]
Wenz et al 2002	124	37	124	164	45	65	5.6%	-40.00 [-52.73, -27.27]
Wohlrab et al 2004	74	0	27	68	0	23		Not estimable
Woolson et al 2004	97	0	50	105	0	85		Not estimable
Wright et al 2004	71.4	11.2	42	77.7	13.2	42	8.3%	-6.30 [-11.54, -1.06]
Yang et al 2009	77.5	13.39	55	73.67	14.51	55	8.4%	3.83 [-1.39, 9.05]
Total (95% CI)			**1077**			**1066**	**100.0%**	**-4.65 [-9.45, 0.15]**

Heterogeneity: Tau² = 64.71; Chi² = 138.72, df = 13 (P < 0.00001); I² = 91%
Test for overall effect: Z = 1.90 (P = 0.06)

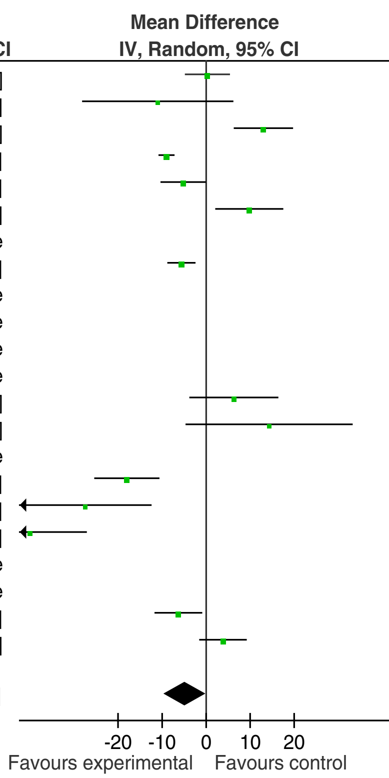


Fig. 3 Forest plot to illustrate mean difference in Harris hips score between minimally invasive surgery (MIS) and conventional total hip arthroplasty (THA) procedures

Table 3 Meta-analysis results of clinical outcomes

Outcome	Groups (*n*)		Studies (*n*)	Overall effect		
	MIS	Conv		Effect estimate	95% CI	*p*-value
Incision length	869	803	17	−7.56	−8.17, −6.95	<0.0001
Intraoperative blood loss	621	656	12	−42.44	−60.14, −24.73	<0.0001
Length of stay	840	856	15	−0.59	−1.07, −0.12	0.01
VAS pain[a]	359	339	7	−0.55	−0.97, −0.13	0.01
Harris hip score	784	797	17	1.49	0.08, 3.06	0.06
Surgical duration	1077	1066	22	−4.65	−9.45, 0.15	0.06
Required blood transfusion	95	133	7	0.75	−0.56, 1.02	0.06
WOMAC score	402	419	6	2.55	−0.75, 5.84	0.13
Blood loss in drain	200	195	6	−53.46	−133.55, 26.62	0.19
Oxford hip score	169	170	2	−0.92	−2.62, 0.77	0.29
Total blood loss	738	701	15	−43.09	−135.79, 49.62	0.36

MIS minimally invasive surgery, *Conv* conventional surgery, *CI* confidence interval

[a] Standardised mean difference

more frequently mal-positioned in MIS compared to conventional approaches. Similarly, they reported a significantly higher percentage of cementless stems in the MIS cohort had a poor fit and fill with less than 2 mm between the distal portion of the stem and the femoral cortex (p= 0.004). They related this to the reduced visualisation of the acetabulum and proximal femur from the small incision. Given the findings of this study, such issues in implant positioning do not seem to be supported by the literature. Nonetheless, since we were unable to distinguish the results between experienced and in-experienced MIS surgeons, it remains unclear whether this factor was important when generalising this complication to general clinical practice. Furthermore, since the longest follow-up period documented was five years [9, 23], it remains unclear whether the affect of implant positioning has any longer-term effect on prosthesis survival. Future surveillance studies of longer follow-up will enlighten as to whether this is a potential feature of MIS THA procedures.

Although this meta-analysis reported no statistically significant difference between surgical exposure method and wound healing complications (p=0.17), the effect size was substantial between the groups with nearly a three times greater risk following MIS compared to conventional THA in the overall analysis. As Table 5 demonstrates, this outcome was measured in a small number of subjects. Accordingly, this conclusion may be attributed to type II statistical error [28]. Such an effect size for this outcome may be attributed to the extensive use of retractors in MIS procedures. Noble et al. [31] reported that during MIS THA, large pressures can develop between the retractors and the wound edges, predisposing to wound healing complications. They recommended that surgeons should consider using the largest possible incision within the realms of MIS principles, and that the precise anatomical placement should be carefully considered to minimise the duration of tissue compression whilst ensuring adequate visualisation of the surgical field [31].

Table 4 Meta-analysis results of radiological outcomes

Outcome	Groups (*n*)		Studies (*n*)	Overall effect		
	MIS	Conv		Effect estimate	95% CI	*p*-value
Femoral offset	150	150	3	0.62	−0.77, 2.01	0.38
Leg-length discrepancy	325	300	5	−0.09	−0.32, 0.43	0.42
Femoral positioning (0–5° valgus)	258	177	4	0.57	0.11, 2.85	0.49
Cup positioning (35–50° valgus)	266	311	5	0.82	0.42, 1.59	0.55
Cup inclination angle	750	730	12	0.24	−1.51, 2.00	0.79
Stem alignment (varus/valgus)	314	331	5	0.03	−0.38, 0.43	0.90

MIS minimally invasive surgery, *Conv* conventional surgery, *CI* confidence interval

Study or Subgroup	MIS Events	MIS Total	Conventional Events	Conventional Total	Weight	Odds Ratio M-H, Fixed, 95% CI
Chen et al 2009	27	83	0	83	4.0%	81.28 [4.86, 1359.86]
Chimento et al 2005	0	28	0	32		Not estimable
Kim 2006	1	70	1	70	11.7%	1.00 [0.06, 16.31]
Laffosse et al 2006	1	42	1	58	9.7%	1.39 [0.08, 22.88]
Laffosse et al 2007	0	58	1	58	17.6%	0.33 [0.01, 8.21]
Sculco et al 2004	0	42	0	42		Not estimable
Speranza et al 2007	2	50	0	50	5.6%	5.21 [0.24, 111.24]
Szendroi et al 2006	2	38	0	21	7.1%	2.95 [0.13, 64.26]
Vicente et al 2008	0	34	1	42	15.7%	0.40 [0.02, 10.16]
Wenz et al 2002	2	124	1	65	15.3%	1.05 [0.09, 11.79]
Wohlrab et al 2004	6	27	0	23	4.9%	14.21 [0.75, 267.52]
Woolson et al 2004	1	50	1	85	8.6%	1.71 [0.10, 28.03]
Wright et al 2004	0	42	0	42		Not estimable
Total (95% CI)		**688**		**671**	**100.0%**	**5.11 [2.52, 10.36]**
Total events	42		6			

Heterogeneity: $Chi^2 = 13.84$, df = 9 (P = 0.13); $I^2 = 35\%$
Test for overall effect: Z = 4.51 (P < 0.00001)

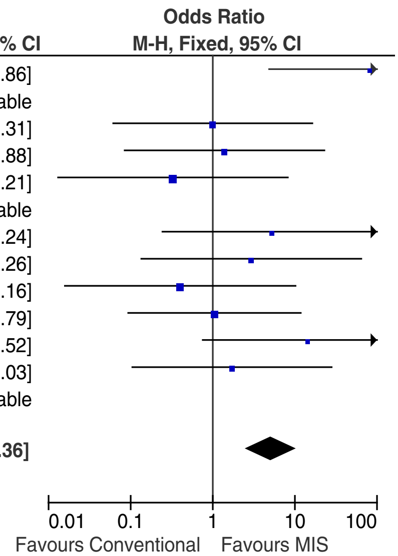


Fig. 4 Forest plot to illustrate odds ratio for incidence of iatrogenic nerve injury between minimally invasive surgical (MIS) and conventional total hip arthroplasty (THA) procedures

There is a lack of consensus over the actual definition of MIS and the relationship between skin incision and soft tissue trauma. Speranza et al. [32] and Procyk [33] suggested that the ideal MIS is that of a procedure which has little tissue disruption without cutting muscles and tendons and therefore less pain to provide a significantly shorter rehabilitation with longer-term outcomes which are equal or better to a conventional approach. Accordingly, the little difference in outcomes reported in this meta-analysis may be attributed to similarities in the operative procedure after the skin incision for traditional and MIS procedures.

An increase in perioperative cytokine level has been demonstrated to correlate with surgical trauma [34]. Both Ogonda et al. [35] and Chimento et al. [6] reported no significant difference between the minimally invasive and conventional THA exposure for cytokine level suggesting that whilst the skin incision may be reduced, tissue trauma is similar between the groups for this procedure. Nonetheless, these findings may however be dependent on the surgical approach adopted and the degree of soft tissue dissection. For instance, in a mini-posterior if the femoral head can be excised without dislocating the hip, there will be less trauma to muscles and capsule unlike the antero-lateral approach [36, 37]. Further assessment of surgical approach and dissection is therefore warranted.

Whilst we did not assess the difference in outcomes between the different types of MIS, as Table 2 demonstrated a number of different surgical approaches were adopted under the term ‘minimally invasive’. Further study is required to determine whether there is a difference in outcomes between the different MIS procedures used during THA. Nonetheless, theoretically, this factor may be associated with different outcomes and, in particular, the incidence of iatrogenic nerve injury. The anterior approach (as part of the Smith-Peterson approach) may be associated with lateral femoral cutaneous nerve injury which was 17 times more likely to occur with MIS compared to standard incision surgery [29]. Given this important complication, further study is recommended to compare the outcomes of different MIS procedures undertaken in THA surgery to determine the efficacy of each approach taken.

Study or Subgroup	MIS Events	MIS Total	Conventional Events	Conventional Total	Weight	Odds Ratio M-H, Random, 95% CI
Chen et al 2009	27	83	0	83	35.5%	81.28 [4.86, 1359.86]
Szendroi et al 2006	2	38	0	21	31.1%	2.95 [0.13, 64.26]
Wohlrab et al 2004	6	27	0	23	33.4%	14.21 [0.75, 267.52]
Total (95% CI)		**148**		**127**	**100.0%**	**16.18 [2.24, 116.71]**
Total events	35		0			

Heterogeneity: $Tau^2 = 0.80$; $Chi^2 = 2.71$, df = 2 (P = 0.26); $I^2 = 26\%$
Test for overall effect: Z = 2.76 (P = 0.006)

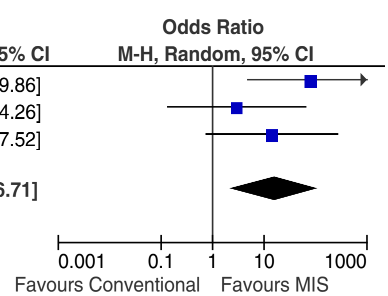


Fig. 5 Forest plot to illustrate odds ratio for incidence of transient lateral femoral cutaneous nerve injury between minimally invasive surgical (MIS) and conventional total hip arthroplasty (THA) procedures

Table 5 Meta-analysis results of complications

Outcome	Groups (*n*)		Studies (*n*)	Overall effect		
	MIS	Conv		Effect estimate	95% CI	*p*-value
Iatrogenic nerve palsy	650	650	13	5.27	2.55, 10.91	<0.0001
Transient lateral femoral cutaneous nerve injury	148	127	3	16.18	2.24, 116.71	0.006
Haematoma formation	270	201	4	2.48	0.85, 7.21	0.09
Sciatic nerve palsy	160	195	3	4.38	0.70, 27.20	0.11
Wound complication	112	141	3	2.99	0.62, 14.35	0.17
Deep vein thrombosis	529	509	9	0.49	0.18, 1.35	0.17
Dislocation	929	918	16	0.65	0.33, 1.26	0.20
Intraoperative fracture	563	568	10	1.52	0.76, 3.04	0.23
Heterotrophic ossification	85	85	2	0.32	0.05, 2.10	0.24
Acetabular component loosening	316	324	6	2.40	0.52, 10.98	0.26
Periprosthetic fracture	212	223	4	0.67	0.27, 1.69	0.40
Required revision surgery	230	250	5	0.72	0.15, 3.50	0.68
Deep infection	594	540	9	0.82	0.22, 2.97	0.76
Superficial wound infection	620	609	10	11.08	0.35, 3.37	0.89
Femoral component loosening	222	222	NE	NE	NE	NE

MIS minimally invasive surgery, *Conv* conventional surgery, *CI* confidence interval, *NE* not estimatable

Surgical learning curve is an important variable which may have accounted for the differences in surgical duration between the groups [30, 38–40]. Desser et al. [41] and Pagnano et al. [42] reported that the MIS technique was more difficult than the conventional exposure method, but that complication rates would be expected to decrease with surgical experience [41, 43]. Whilst some authors have reported a low complication rate such as Berry et al. [13] of 2% with four experienced surgeons, others have reported much higher rates such as Pagnano et al. [42] conversely with 14%, which was attributed to surgical experience and the existence of a learning curve [13, 43]. Goosen et al. [44] concluded that relatively inexperienced surgeons should consider carefully the advantages and disadvantages of MIS procedures before adopting such an approach given the long learning curve. Furthermore, Sculco et al. [23] suggested that the posterior approach may be the most appropriate approach to adopt since it is familiar to most surgeons and still allows the easy extension of the wound if operative visibility is insufficient [23, 45].

When considering its application in clinical practice, previous authors have suggested that not all patients are suitable candidates for MIS THA procedures [41]. Those patients who are thin and young, and with a lower risk of peri- or postoperative complication would be most suitable for MIS [46]. However, as Desser et al. [41] commented, these characteristics may not be reflective of the average hip surgeon's caseload. Sculco et al. [23] suggested that patients with a body mass index greater than 30 should not be considered for MIS due to the difficulty in identifying anatomical landmarks during surgery. Howell et al. [38] also suggested that patients with excessively stiff hips, those with severe dysplasia requiring larger visualisation to manage the distorted acetabular anatomy and correct any femoral shortening or derotation, and those with a marked distortion of the proximal femur may also be unsuitable for MIS THA. For such larger patients a secondary incision may be required distally to allow adequate acetabular reaming [47].

Advocates of the MIS technique have suggested that the smaller skin incision provides improved cosmesis and increased patient satisfaction. Only one study has previously assessed the outcomes of scar cosmesis following conventional or MIS THA [48]. Whilst all patients considered their scars acceptable in appearance, when reviewed by plastic surgeons masked to surgical procedure, the cosmesis of the mini-posterior approach was more frequently reported as poorer than the standard posterior approach. Mow et al. [48] attribute these findings to skin and soft tissue damage caused by the high retractor pressure required for the MIS exposure.

Conclusions

The findings of this study indicate whilst there is little difference in the clinical or radiological outcomes of MIS to conventional THA, MIS procedures pose a significantly increased risk of transient lateral femoral cutaneous nerve palsy than traditional techniques.

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Conflict of interest The authors declare that they have no conflict of interest

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