



# Outcomes and complications of the INFIX technique for unstable pelvic ring injuries with high-velocity trauma: a systematic review and meta-analysis

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## Abstract

**Background** The pelvic INFIX technique has been proposed as a useful alternative to symphyseal plating for management of unstable pelvic ring injuries. The minimally invasive nature of the procedure, shorter operative time and less perioperative blood loss have been purported as potential advantages.

**Questions/purposes** This systematic review and meta-analysis were conducted to determine the outcomes and complications of the INFIX technique for unstable pelvic ring injuries.

**Methods** A systematic review of literature was performed on the PubMed, EMBASE and Scopus databases. Prospective and retrospective studies in all languages, whether comparative or non-comparative, pertaining to the use of INFIX in pelvic fractures were included. Studies which did not evaluate INFIX, case reports, conference abstracts and those with less than 10 cases were excluded. Cadaveric studies, technique papers and studies that did not describe the prespecified outcome measures were also excluded. Meta-analysis consisted of two different arms: a *comparative arm*, to compare INFIX to symphyseal plating, and a *non-comparative meta-analysis arm*, to determine pooled rates of outcomes and complications. Risk of bias was determined by the Methodological Index for Non-Randomised Studies (MINORS) tool.

**Results** A total of 22 studies were included in the systematic review, of which 7 were comparative and 15 were non-comparative. 746 patients were included for qualitative analysis and pooled analysis done for 589 patients. The average follow-up of these studies ranged from a minimum of 5.4 months to a maximum of 54 months. Comparative meta-analysis ( $n=3$  studies) of plating and INFIX showed significantly lesser blood loss (mean difference = 176.46 mL; 95% CI - 207.54 to - 145.38) and shorter operative time (mean difference = 26.43 min, 95% CI - 31.79 to - 21.07) with INFIX, but no significant difference in the overall complication rates (OR 1.59, 95% CI 0.83–3.05) and functional outcome scores (mean difference = - 2.51, 95% CI - 5.73 to 0.71). Pooled analysis showed overall good radiological (mean percentage of excellent to good reduction = 91.4%, 95% CI 0.860–0.969) and functional outcomes (mean Majeed score = 86.48, 95% CI 83.34–89.61) with INFIX. The most common complications were lateral femoral cutaneous nerve (LFCN) injury (overall rate 28%, 95% CI 15.1–41%) and heterotopic ossification (HO) (overall rate 9.4%, 95% CI 5.5–13.3%); rates of other complications were low. Significant heterogeneity was noted in the pooled analysis of blood loss, operative time, functional outcome, HO and LFCN injury. The overall strength of evidence was found to be weak.

**Conclusion** The INFIX technique can be considered as a viable alternative to symphyseal plating for unstable pelvic ring injuries. It has the advantages of shorter operative times and less blood loss, along with comparable functional outcomes, when compared to plating. Overall, good functional outcomes can be expected. However, well-designed, multi-center randomized controlled trials are needed to conclusively prove the benefit of this technique.

**Keywords** INFIX · Outcomes · Complications · Efficacy

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## Introduction

Pelvic ring injuries are potentially life threatening and necessitate multidisciplinary care [1]. Surgical management of these injuries has revolved around the use of

open reduction and internal fixation with plates, iliosacral screws and external fixation [2]. Simple injury patterns like diastasis can be managed well with plates, but complex anterior ring fractures were traditionally managed with external fixation as these can be quite challenging. However, external fixators have been associated with complications like pin site infection, limited access to the abdomen, decreased patient mobility, loosening and nerve damage, and are therefore not tolerated well by patients [3].

To overcome these limitations, the anterior subcutaneous internal fixator (ASIF) was developed from spine surgery instrumentation. This modality, termed as the *INFIX* or the *pelvic bridge* technique, utilizes pedicle screws that are placed into the ilium on either side, and connected to each other with a subcutaneous rod, with or without fixation into the symphyseal region [4]. The proposed potential benefits include fewer soft tissue infections, better pain control and patient mobilization and hence faster rehabilitation. Moreover, this technique is minimally invasive and therefore thought to be less time-consuming and associated with less blood loss.

This technique has been used for more than a decade, and several studies have reported clinical and functional outcomes with this technique. However, there is a need to critically analyze the available evidence in a comprehensive fashion so as to determine its efficacy and safety in routine surgical practice, as well as to refine its indications. Therefore, the aim of this study was to conduct this systematic review and meta-analysis to determine the outcomes and complications of the *INFIX* technique for unstable pelvic ring injuries following high-velocity trauma.

## Methods

### Objectives

1. To determine the clinical and radiological outcomes of the *INFIX* technique for unstable pelvic ring injuries.
2. To determine the complication rates of the *INFIX* technique for unstable pelvic ring injuries.

### Study design

A systematic review and meta-analysis of literature were planned and in accordance with the PRISMA guidelines [5].

### Inclusion and exclusion criteria

Prospective and retrospective studies in all languages, whether comparative or non-comparative, pertaining to the use of *INFIX* in pelvic fractures, with a minimum of 10 cases were included. Studies which did not evaluate *INFIX*, case reports, conference abstracts and those with less than 10 cases were excluded. Cadaveric studies and technique papers that did not describe the prespecified outcome measures were also excluded. Since this study involved unstable pelvic ring injuries with high-velocity trauma, *INFIX* used for fragility fractures of the pelvis were not included.

### Search methodology

Using a well-defined search strategy, a primary search was conducted on PubMed, Scopus and Embase on 18 May 2020 (Table 1). A total number of 384 results were obtained. The secondary search was conducted by screening the references from included studies and other relevant publications on the subject.

**Table 1** The detailed search methodology

Database	Search strategy	Results
PubMed 18/05/2020	(( <i>INFIX</i> [All Fields] OR (anterior[All Fields] AND subcutaneous[All Fields] AND ("fracture fixation, internal"[MeSH Terms] OR ("fracture"[All Fields] AND "fixation"[All Fields] AND "internal"[All Fields]) OR "internal fracture fixation"[All Fields] OR ("internal"[All Fields] AND "fixation"[All Fields]) OR "internal fixation"[All Fields]))) OR (anterior[All Fields] AND subcutaneous[All Fields] AND ("pelvis"[MeSH Terms] OR "pelvis"[All Fields] OR "pelvic"[All Fields]) AND fixator[All Fields])) AND (("pelvis"[MeSH Terms] OR "pelvis"[All Fields] OR ("pelvis"[MeSH Terms] OR "pelvis"[All Fields] OR "pelvic"[All Fields]) AND ("fractures, bone"[MeSH Terms] OR ("fractures"[All Fields] AND "bone"[All Fields]) OR "bone fractures"[All Fields] OR "fracture"[All Fields])))	63
EMBASE 18/05/2020	(anterior AND subcutaneous AND internal AND ('fixation'/exp OR fixation) OR (anterior AND subcutaneous AND pelvic AND fixator) OR infix) AND ('pelvis' OR 'pelvis fracture')	52
SCOPUS 18/05/2020	(( ALL ( anterior AND subcutaneous AND internal AND fixation) OR ALL ( anterior AND subcutaneous AND pelvic AND fixator) OR ALL ( infix))) AND (( ALL ( pelvis) OR ALL ( pelvic AND fracture)))	269
Total		384

## Study selection

The selection of studies was done independently by two reviewers (SP and KJ). Titles and abstracts of the search results were screened initially. This was followed by retrieval of the full texts of relevant articles. Articles were included if they fulfilled the pre-specified inclusion criteria. For studies reported by the same author, all studies were included in the systematic review, but the study with maximum number of patients was included for analysis. Discrepancies were resolved by mutual agreement.

## Data collection, data items and outcome measures

Data collection was performed by KJ and SS on a pre-piloted data collection sheet; all entries were cross-checked by SP to ensure accuracy. The following baseline data items were extracted: Journal and year of publication, language, gender, age, injury severity score (ISS and fracture classification).

Outcome measures that were extracted included perioperative blood loss and time, functional and radiological outcomes, Majeed scoring and complications.

## Risk-of-bias assessment

The Methodological Index for Non-Randomised Studies (MINORS) tool [6] was used to assess the risk-of-bias for all studies by 2 independent observers (SS and VK) (Table 2). This tool is a 12-item questionnaire that can be used for both comparative and non-comparative studies. Grading is done from a score of 16 for non-comparative and 24 for comparative studies.

## Data synthesis and analysis

Qualitative and quantitative analyses were performed after data extraction. For qualitative analysis, the data were organized in appropriate tables. Quantitative data synthesis consisted of two different arms: a *comparative meta-analysis arm* and a *non-comparative meta-analysis arm*.

The *comparative meta-analysis arm* was conducted to determine the differences in outcomes and complications between INFIX and plating for unstable pelvic ring injuries. A random-effects model was employed for this purpose; measures of treatment effects included mean difference (MD) for continuous variables (such as functional outcome score, perioperative blood loss, operative time) and odds ratio (OR) for dichotomous variables (such as complications). 95% confidence intervals (CI) were calculated for each outcome of interest. The  $I^2$  test was used to assess statistical heterogeneity. Forest plots were constructed to provide a visual summary for each outcome of interest. The RevMan 5.4 software was used for these analyses [7].

The non-comparative meta-analysis arm was conducted to determine the pooled effect size for outcomes and complication rates. Outcome measures included event rate for dichotomous variables and mean for continuous variables; 95% CI were calculated for each outcome of interest. The  $I^2$  test was used to assess statistical heterogeneity. Forest plots were constructed to provide a visual summary for each outcome of interest. All analyses were performed by the Open MetaAnalyst software [8].

## Exploration of heterogeneity

For outcomes which showed high statistical heterogeneity ( $I^2 > 75\%$ ), leave-one-out meta-analysis and meta-regression (by a random-effects model) were performed. To facilitate meta-regression, the following covariates were studied:

- the percentage of complex cases in the study (defined as the percentage of vertical shear and/or combined mechanism injuries, or Tiles C) (continuous variable).
- total cases (continuous variable).
- ethnicity—Asian versus non-Asian study population (dichotomous variable).

## Subgroup analysis

Subgroup analysis was done by dividing the studies into those with patients of Asian ethnicity versus those of non-Asian ethnicity.

## Results

### Literature search

The PRISMA flowchart for the study has been presented in Fig. 7. A total of 384 records were identified, and full text retrieved for 49 studies. Twenty-seven studies were excluded as per the exclusion criteria, and a total of 22 studies were included for qualitative analysis [9–30]. The details of these studies are presented in Table 3. Comparative meta-analysis was performed on 3 studies that compared INFIX with plating [12, 25, 30] and pooled analysis was performed on 18 studies.

### Characteristics of study

A summary of the studies included in the review has been presented in Table 4. A total of 746 patients were included for qualitative analysis; of these, pooled analysis was done for 589 patients. The average follow-up of these studies ranged from a minimum of 5.4 months to a maximum of 54 months. The mean time to radiological union was

**Table 2** MINORS tool for risk of bias assessment

Study	Clearly stated aim	Inclusion of consecutive patients	Prospective data collection	Endpoints appropriate to study aim	Unbiased assessment of study endpoint	Follow-up period appropriate to study aim	<5% lost to follow-up	Prospective calculation of study size	Adequate control group	Contemporary groups	Baseline equivalence of groups	Adequate statistical analyses	Total	Grade
Du [9]	2	1	2	2	1	2	2	0	N/A	N/A	N/A	N/A	12/16	Fair
Steer [10]	2	1	2	2	1	2	1	0	N/A	N/A	N/A	N/A	11/16	Fair
Liu [11]	2	2	2	2	1	1	2	0	2	2	2	0	18/24	Fair
Yin [12]	2	2	2	2	1	2	2	0	2	2	2	2	21/24	Good
Hua [13]	2	1	2	2	1	2	2	0	N/A	N/A	N/A	N/A	12/16	Fair
Ding [14]	2	2	2	2	1	2	2	0	2	2	2	0	19/24	Fair
Shetty [15]	2	1	2	2	1	2	2	0	N/A	N/A	N/A	N/A	12/16	Fair
Wu [16]	2	1	2	2	1	2	2	0	N/A	N/A	N/A	N/A	12/16	Fair
Wang [17]	2	1	2	2	1	2	2	0	2	2	2	2	20/24	Fair
Fang [18]	2	1	2	2	1	2	2	0	N/A	N/A	N/A	N/A	12/16	Fair
Vaidya [19]	2	1	2	2	1	2	1	0	N/A	N/A	N/A	N/A	11/16	Fair
Vaidya [20]	1	1	2	1	1	2	2	0	N/A	N/A	N/A	N/A	10/16	Poor
Hoskins [21]	2	1	2	1	1	2	2	0	N/A	N/A	N/A	N/A	11/16	Fair
Muller [22]	2	1	2	2	1	2	1	0	N/A	N/A	N/A	N/A	11/16	Fair
Vaidya [23]	2	1	2	2	1	2	1	0	N/A	N/A	N/A	N/A	11/16	Fair
Gardner [24]	1	1	2	2	1	2	0	0	N/A	N/A	N/A	N/A	9/16	Poor
Vaidya [25]	2	1	2	2	1	2	2	0	2	2	2	2	20/24	Fair
Zhang [26]	1	1	2	1	1	2	2	0	N/A	N/A	N/A	N/A	10/16	Poor
Kuttner [27]	1	1	2	2	1	2	1	0	N/A	N/A	N/A	N/A	10/16	Poor
Bi [28]	2	1	2	2	1	2	2	0	2	2	2	2	20/24	Fair
Dahill [29]	2	1	2	2	1	2	2	0	N/A	N/A	N/A	N/A	12/16	Fair
Wang [30]	2	1	2	2	1	2	2	0	N/A	N/A	N/A	N/A	12/16	Fair

**Table 3** Characteristics of studies included

Study design	
Prospective	
Comparative	2
Non-comparative	4
Retrospective	
Comparative	5
Non-comparative	11
Level of evidence	
Level 4	6
Level 5	16
Language	
English	21
Non-English	1
Technique of INFIX used <sup>a</sup>	
Conventional technique	17
Modified 3 screw technique	2
Robot assisted	4
Modified 4 screw technique	1

<sup>a</sup>2 studies that compared two different techniques of pelvic INFIX were included as separate studies for review

reported in 3 studies with an average time of 4.1 months [11, 15, 18].

### Comparative meta-analysis—plating versus INFIX (Fig. 1)

Comparative meta-analysis revealed significantly less blood loss with the INFIX procedure as compared to plating (mean difference = 176.46 mL; 95% CI – 207.54 to – 145.38) and significantly shorter operative time (mean difference = 26.43 min, 95% CI – 31.79 to – 21.07) and no significant difference in the overall complication rates (OR 1.59, 95% CI 0.83–3.05) and functional outcome score (MD – 2.51, 95% CI – 5.73 to 0.71).

### Pooled analysis

#### Perioperative events

The pooled mean operative time estimated from 12 studies (330 patients) was 52.1 min (95% CI 43.69–60.51); the heterogeneity for this estimate was high ( $I^2 = 99.42\%$ ,  $p < 0.01$ ) (Fig. 2). Meta-regression revealed that the high heterogeneity was not explained by the percentage of complex pelvic injury cases, total number of cases or the surgical volume (less than or more than 25 cases).

The pooled mean blood loss estimated from 10 studies (266 patients) was 65.425 mL (95% CI 51.022–79.828);

the heterogeneity for this estimate was high ( $I^2 = 99.61\%$ ,  $p < 0.001$ ) (Fig. 2). Covariate analysis for the percentage of complex cases (vertical shear or combined type/tiles type C) showed significant increase in blood loss with the increase in complex cases ( $p = 0.03$ ).

### Outcomes (Table 5)

#### Radiological outcomes

The quality of reduction was reported as per Matta's criteria [31] by 7 studies in 161 patients. Pooled analysis showed an excellent to good reduction in 91.4% of the cases (95% CI 0.860–0.969), with a moderate heterogeneity ( $I^2 = 45.26\%$ ,  $p = 0.09$ ) (Fig. 3).

#### Functional outcomes

Majority of the studies reported Majeed scoring [32]. Only 1 study [10] used the Iowa pelvic score as they consider it to have the best correlation with SF-36 and is a good tool for measuring outcomes in severe pelvic injury. Pooled analysis of 8 studies reporting Majeed score showed an average score of 86.48 (95% CI 83.34–89.61); the heterogeneity for this event was high ( $I^2 = 92.37\%$ ,  $p < 0.01$ ) (Fig. 3). Meta-regression analysis showed that better Majeed score was obtained with complex fracture patterns ( $p = 0.001$ ).

Outcome scoring classified as excellent or good was reported in 82.8% cases in 10 studies with 228 patients (95% CI 73.7–91.9%); the heterogeneity for this event was high ( $I^2 = 82.24\%$ ,  $p < 0.001$ ) (Fig. 3). Meta-regression showed a trend of poorer results with complex patterns but was not statistically significant ( $p = 0.118$ ). Leave-one-out analysis excluding Kuttner et al. [27] improved overall estimate from 82.8 to 88.2% (95% CI 81.9–94.5%).

### Complications

The complications of the INFIX procedure have been presented in Table 6.

#### Non-union

Only 2 cases of non-union have been reported in literature. Muller et al. [22] reported nonunion in a schizophrenic non-compliant patient while Dahill et al. [29] reported 1 asymptomatic nonunion. Pooled analysis showed an overall nonunion rate of 1.2% (95% CI 0.4–2.1%); the heterogeneity for this event was low ( $I^2 = 0\%$ ,  $p = 1.000$ ) (Fig. 4).

**Table 4** Summary of the studies included

S. no.	Author	Language	Technique	No. of patients	Male/ female	Age±SD	ISS	Operative time (mins)	Blood loss (mL)	Classification	Titles												Implant removal	Average follow-up (months)		
											Young and Burgess						Tiles									
											LC1	LC2	LC3	APC1	APC2	APC3	VS	C	BI	B2	B3	C1			C2	C3
1	Du [9]	Eng-lish	Robot assisted	17	12/5	40.1±3.8	-	112.9±16.8	105.9±20.6	-	-	-	-	-	-	7	2	-	8	-	-	-	-	-	6.7	
2	Steer [10]	Eng-lish	Conventional	24	19/5	38.5	29.8	-	-	-	7	3	2	-	-	7	5	-	-	-	-	-	-	-	20.4 weeks	6
3	Liu [11]	Eng-lish	Robot assisted	24	15/9	37.4±6.6	-	65.4±17.5	35.0±7.2	-	-	-	-	-	-	17	7	-	-	-	-	-	-	-	16–18 weeks	5.4
4	Liu [11]	Eng-lish	Conventional	21	13/8	39.8±7.1	-	86.7±23.75	46.2±9.3	-	-	-	-	-	-	14	7	-	-	-	-	-	-	-	16–18 weeks	5.4
5	Yin [12]	Eng-lish	Conventional	35	19/16	41.7±12.6	29	70.3±11.8	97.1±15.6	-	-	-	-	-	-	6	12	7	4	6	-	-	-	-	27	
6	Hua [13]	Eng-lish	Conventional	23	12/11	37.6±11.6	-	60±6.4	150±17.8	-	-	-	-	-	-	6	4	3	10	-	-	-	-	-	13.5	
7	Ding [14]	Eng-lish	Modified	25	13/12	39.3±16.7	-	54.8±10.7	35.3±9.2	-	-	-	-	-	-	5	14	6	-	-	-	-	-	-	6.3±1.8 months	12
8	Ding [14]	Eng-lish	Conventional	26	11/15	35.2±15.9	-	32.3±9.9	24.5±7.1	-	-	-	-	-	-	5	16	5	-	-	-	-	-	-	6.3±1.8 months	12
9	Shetty [15]	Eng-lish	Conventional	15	8/7	37.7±12.5	26.2±1.8	29.9±2.9	115.3±26.7	1	-	-	-	-	-	13	-	1	1	-	-	-	-	-	7.3 months	34.9
10	Wu [16]	Eng-lish	Modified	23	13/10	36.3±9.25	21.2	26.6±5.25	29.1±4.25	-	-	-	-	-	-	3	7	8	5	-	-	-	-	-	15	
11	Wang [17]	Eng-lish	Modified	26	16/10	39.3±17	-	91.2±13.0	57.5±16.9	-	-	-	-	-	-	8	13	5	-	-	-	-	-	-	4.3 months	8.2
12	Fang [18]	Eng-lish	Conventional	29	8/21	64.2±17.75	-	-	-	19	2	5	1	1	1	1	-	19	7	1	1	1	1	1	-	7.2
13	Vaidya [19]	Eng-lish	Conventional	83	57/26	41.67±15.9	22.75±11.2	-	-	7	18	13	7	10	18	6	11	19	13	24	7	5	5	5	5.3 months	35
14	Vaidya [20]	Eng-lish	Conventional	24	15/9	40.3±12.5	-	-	-	-	1	4	3	2	14	-	-	2	6	8	3	5	5	5	5.4 months	19
15	Hoskins [21]	Eng-lish	Conventional	21	-	39±14.25	23	51±5.25	-	12	6	-	1	2	-	-	-	-	-	-	-	-	-	-	109 days	11.5
16	Muller [21]	Eng-lish	Conventional	36	22/14	45.2±3.29	25.17±1.72	-	-	-	-	-	-	-	-	-	-	-	-	36	-	-	-	-	9.4 months	54
17	Vaidya [23]	Eng-lish	Conventional	96	56/40	39.2±13.75	-	-	-	5	14	15	16	14	20	7	-	-	-	-	-	-	-	-	-	15
18	Gardner [24]	Eng-lish	Conventional	24	13/11	39±11.5	-	-	-	-	-	-	-	-	-	-	-	-	-	24	-	-	-	-	4 months	12
19	Vaidya [25]	Eng-lish	Conventional	24	18/6	43.38±18.13	22.08±9.08	-	-	4	-	-	-	13	7	-	12	-	-	-	-	-	-	-	3–5 months	40.4
20	Zhang [26]	Eng-lish	Conventional	28	17/11	39.8±12.25	-	24±4.25	15±6.25	8	11	-	3	-	6	-	-	-	-	-	-	-	-	-	-	8.7
21	Kuttner [27]	German	Conventional	22	11/11	44±16.25	-	41±7.75	-	-	-	-	-	-	1	-	-	-	-	21	-	-	-	-	30	
22	Bi [28]	Eng-lish	Modified	21	12/9	37.85±10.31	-	53.90±5.34	33.60±5.34	-	-	-	-	-	5	9	7	-	-	-	-	-	-	-	16.6	

Table 4 (continued)

S. no.	Author	Language	Technique	No. of patients	Male/female	Age±SD	ISS	Operative time (mins)	Blood loss (mL)	Classification										Implant removal	Average follow-up (months)				
										Young and Burgess					Tiles										
										LC1	LC2	LC3	APC1	APC2	APC3	VS	C	BI	B2			B3	CI	C2	C3
23	Dahill [29]	English	Conventional	50	32/18	41±8.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	136 days	38		
24	Wang [30]	English	4 screws	29	19/10	41.79±10.75	-	42.07±3.31	46.14±4.68	-	-	-	-	-	-	-	-	9	-	-	-	-	-	12 months	18.72

### Infection

The overall rate of infection with INFIX was seen to be 2.3% (95% CI 1.1–3.4%); the heterogeneity for this event was low ( $I^2=0\%$ ,  $p=0.971$ ). Seventeen cases of infections have been reported overall in the studies (Fig. 4).

### Loosening

Loosening of implant is a rare complication reported in 7 cases. The overall rate of loosening was found to be 1.3% (95% CI 0.4–2.2%); the heterogeneity for this event was low ( $I^2=0\%$ ,  $p=0.995$ ) (Fig. 4).

### HO

HO though usually asymptomatic is a commonly associated complication with an overall rate of 9.4% (95% CI 5.5–13.3%); the heterogeneity for this event was high ( $I^2=87\%$ ,  $p<0.001$ ). High number of cases of HO have been reported by Vaidya et al. [23] ( $n=32$ ), Hoskins et al. [21] ( $n=14$ ) and Yin et al. [12] ( $n=12$ ) in their studies (Fig. 4). Subgroup analysis was done according to ethnicity (Asians and non-Asians), and it was seen that non-Asians were more susceptible (23.6% versus 4.2% in Asians). Meta-regression according to ethnicity showed a strong correlation ( $p=0.01$ ).

### LFCN injury

LFCN injury, mostly self-limiting is the most commonly seen complication with INFIX. Pooled analysis showed an overall rate of LFCN injury as 28% (95% CI 15.1–41%); the heterogeneity for this event was high ( $I^2=95.7\%$ ,  $p<0.001$ ). Vaidya et al. [23] reported 27 LFCN injuries in a series of 96 patients, while Hoskin et al. [21] reported 20 nerve injuries in 21 cases (42 screws) (Fig. 5). Cumulative meta-analysis shows that from the year 2018, the complication rate of LFCN injury is similar, but despite 9-year experience, the complication rate is stationary around 30%. Subgroup analysis was done according to ethnicity (Asians and non-Asians), and it was seen that non-Asians were more susceptible to LFCN injury (40.9% versus 18.9% in Asians). However, meta-regression according to ethnicity showed a weak correlation ( $p=0.053$ ).

### Deep venous thrombosis (DVT)

Pooled analysis showed that the overall rate of DVT was 1.2% (95% CI 0.3–2.1%); the heterogeneity for this event was low ( $I^2=0\%$ ,  $p=0.926$ ). A total of 8 cases of DVT have been reported in literature (Fig. 6).

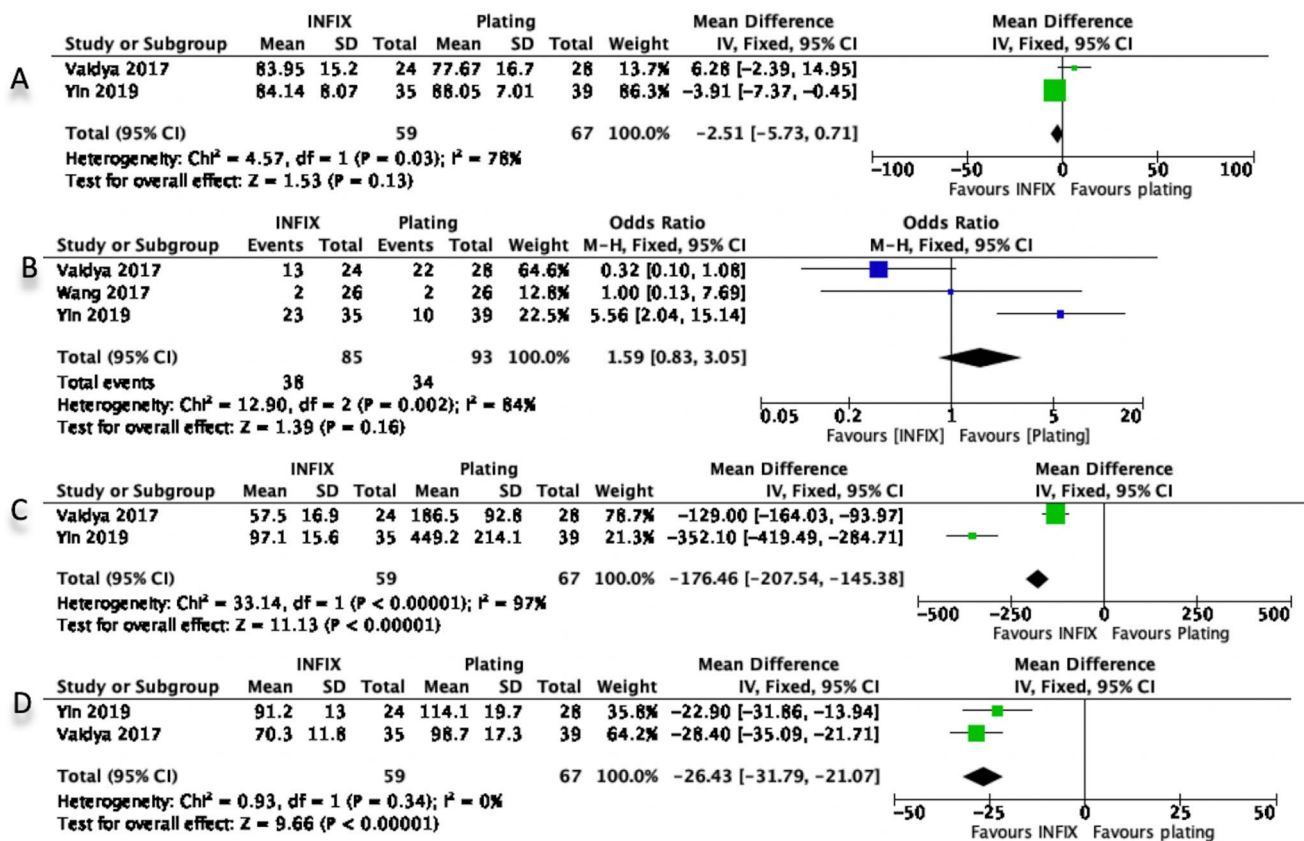


Fig. 1 Forest plots for comparison of INFIX vs plating. a Functional outcomes. b Number of complications. c Blood loss. d Perioperative time

## Femoral nerve injury

Pooled analysis showed that overall rate of femoral nerve injury was 1.3% (95% CI 0.4–2.2%); the heterogeneity for this event was low ( $I^2 = 0\%$ ,  $p = 0.998$ ) (Figs. 6, 7).

## Loss of reduction

Loss of reduction has been reported in 6 cases with overall rate of 1.8% (95% CI 0.7–2.8%); the heterogeneity for this event was low ( $I^2 = 0\%$ ,  $p = 1.000$ ). This loss of reduction has been reported in the immediate post-operative phase, and no study has reported any loss of reduction post-implant removal (Fig. 6).

## Early removal

Early implant removal due to loosening, infection or nerve injury was done in 18 patients with overall rate of 2.1% (95% CI 0.9–3.2%); the heterogeneity for the event was low ( $I^2 = 0\%$ ,  $p = 0.761$ ). However, studies have reported that despite the early removal of implant in these cases, the patients have satisfactory functional outcomes (Fig. 6).

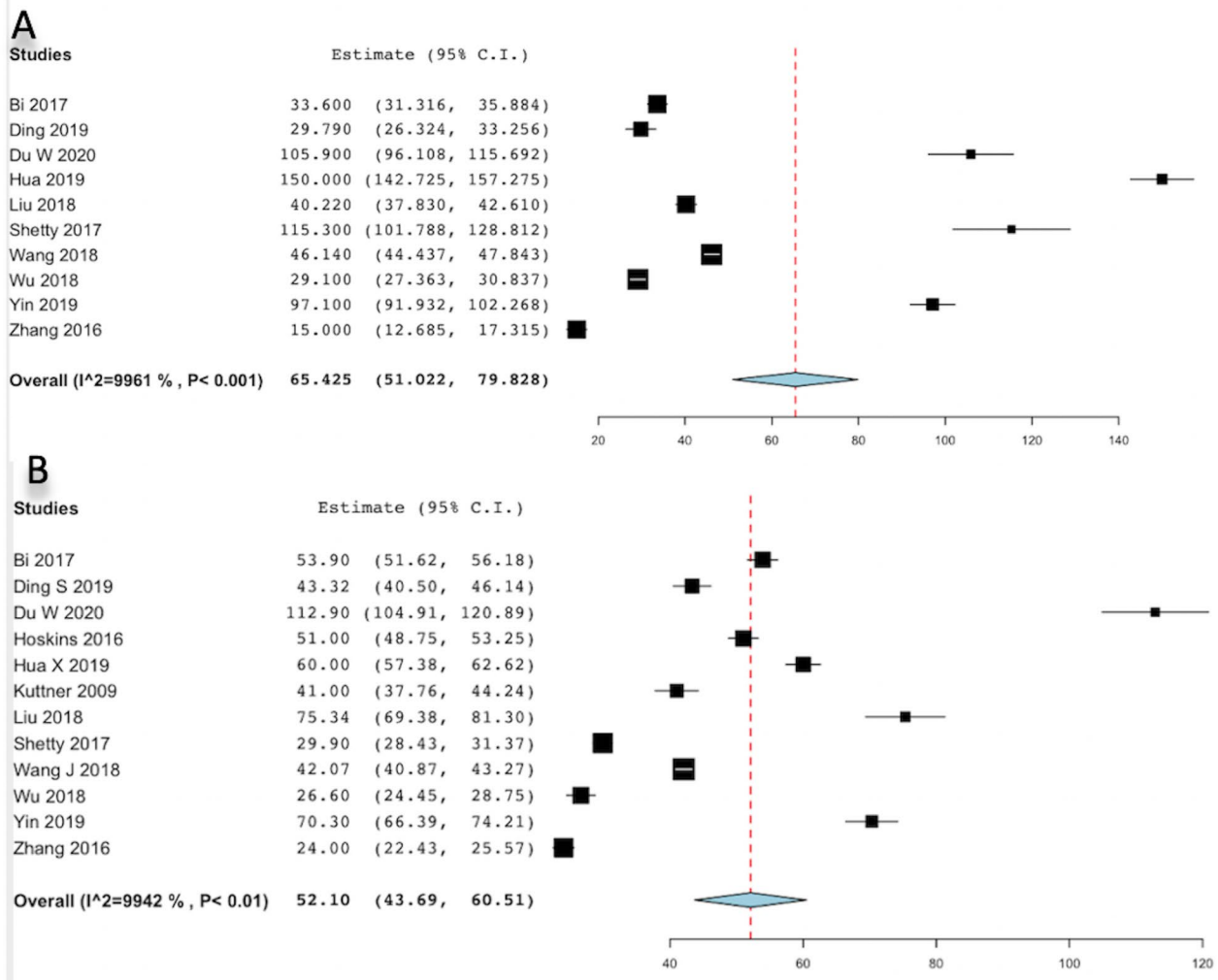
## Risk of bias assessment

The risk of bias assessment is depicted in Table 2 using MINORS tool. For non-comparative studies, 7 studies had a score of 12, 5 had a score of 11, 3 had a score of 10 and 1 had a score of 9. For comparative studies, 1 study had a score of 21, 3 had a score of 20, 1 had a score of 19 and 1 had a score of 18. There were no randomized control trials reported.

## Discussion

Pelvic fractures are complex injuries with disruption of multiple bony or ligamentous components. The indications for anterior fixation with INFIX are unstable pelvic ring injuries (Tiles B and C or Young and Burgess-LC 2 and 3, APC 2 and 3, Vertical Shear and Combined) in conjunction with posterior fixation. Symphyseal injuries are conventionally treated with plating [19, 21]. However, in Types B and C injuries it is associated with extensive exposure and increased complications, and thus the role of INFIX has been developed as a useful modality. The sequence of fixation is usually





**Fig. 2** Forest plots for perioperative events reported in various studies. **a** Blood loss. **b** Intra operative time

posterior fixation followed by anterior fixation. However, Gardner et al. [24] demonstrated that anterior fixation should be considered first for pelvic reduction.

Biomechanical studies done by Vaidya et al. [33], Osterhoff et al. [34], Eagan et al. [35] show that mechanical stiffness of an INFIX construct is similar or superior to that of an external fixator. Monoaxial screws are 26% more rigid than polyaxial screws but are technically more difficult. However, Vgdorchik [36] showed that internal fixation of the anterior ring with plates was still the strongest when compared to INFIX or an external fixator. As such, in patients with pure symphyseal injury, internal fixation is still the preferred treatment.

INFIX being a subcutaneous procedure was associated with relatively low blood loss (mean 65.425 mL). However, no study reported the method of estimation of blood loss which could account for the variability. Moreover, few studies have reported blood loss for anterior and posterior

fixation combined which could be a possible cause of high heterogeneity in our analysis.

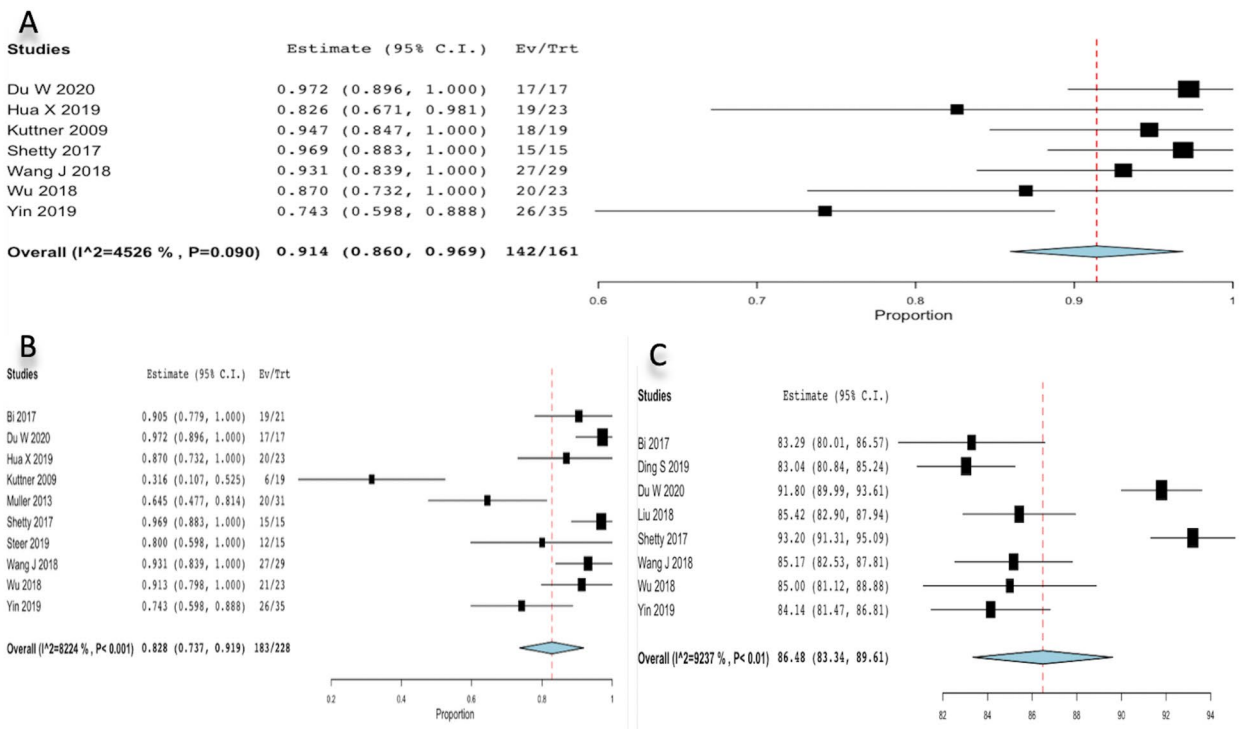
The duration of INFIX fixation was seen to be an average of 52.1 min. The pooled analysis shows that it is a short procedure with excellent results. However, the need for a concomitant surgical procedure such as spino-pelvic fixation by Du et al. [9] increased the operative time in their series. We also observed that being a percutaneous procedure with only indirect reductions being done, the operative time does not increase significantly with complex anterior ring injuries.

Only 2 nonunion cases have been reported in literature which is indicative of a very high union rate, which is also true for pelvic fractures in general. Adequate reduction of fracture fragments is the key for a successful outcome. Outcome scores have mainly reported excellent to good results. These are better in comparison with those studies where anterior external fixators were applied or when

**Table 5** Assessment of radiological and functional outcomes

S. no.	Authors	Radiological outcomes (Matta's)				Mean time to radiological union	Majeed Score	Functional outcome			SF-12	Return to work
		Excellent	Good	Fair	Poor			Excellent	Good	Fair		
1	Du [9]	15	2	0	0	–	91.8±3.8	17	0	0	0	
2	Steer [10]	–	–	–	–	–	IPS: 79.7	5	7	2	1	
3	Liu [11] [R]	–	–	–	–	4.3±0.7 months	86.4±7.2	–	–	–	–	
4	Liu [11] [C]	–	–	–	–	4.5±1.1 months	84.3±10.3	–	–	–	–	
5	Yin [12]	7	19	6	3	–	84.14±8.07	26	–	9	–	20
6	Hua [13]	13	6	4	0	–	–	14	6	2	1	
7	Ding [14] [M]	–	–	–	–	–	83.5±7.8	–	–	–	–	
8	Ding [14] [C]	–	–	–	–	–	82.6±8.2	–	–	–	–	
9	Shetty [15]	12	3	0	0	3.5±0.75 months	93.2±3.74	8	7	0	0	48.58 +/5.61
10	Wu [16]	12	8	3	0	–	85±9.49	14	7	2	0	
11	Wang [17]	–	–	–	–	–	–	21	–	5	–	22
12	Fang [18]	–	–	–	–	14.7 weeks	–	–	–	–	–	
13	Vaidya [19]	–	–	–	–	–	78.8±13.8	–	–	–	–	
14	Vaidya [20]	–	–	–	–	–	–	–	–	–	–	
15	Hoskins [21]	–	–	–	–	–	–	–	–	–	–	
16	Muller [22]	–	–	–	–	–	–	20	–	11	–	26
17	Vaidya [23]	–	–	–	–	–	–	–	–	–	–	
18	Gardner [24]	–	–	–	–	–	–	–	–	–	–	
19	Vaidya [25]	–	–	–	–	–	83.95 + 15.2	–	–	–	–	
20	Zhang [26]	–	–	–	–	–	–	–	–	–	–	
21	Kuttner [27]	10	8	1	0	–	–	3	3	12	1	16
22	Bi [28]	–	–	–	–	–	83.29±7.68	10	9	2	0	
23	Dahill [29]	–	–	–	–	–	–	–	–	–	–	
24	Wang [30]	16	11	2	0	–	85.17±7.25	15	12	2	0	

IPS IOWA Pelvic Score, R robot assisted, M modified technique, C conventional technique



**Fig. 3** Forest plots for studies reporting outcomes **a** radiological, **b** functional, **c** Majeed Score

injuries were left conservatively to heal on their own [15]. However, many pelvic ring injuries are associated with multiple other injuries that affect the overall outcome and make it impossible to assess treatment [19]. For these, patient-reported outcome scores have been developed which may need to be reported more in the forthcoming studies.

No procedure is without complications and INFIX has been associated with LFCN injury, HO, vascular injury, DVT, femoral nerve palsy and surgical site infection.

LFCN injury is a common complication but is usually self-limiting. Rudin et al. [37] studied in detail the anatomical variations of LFCN in 18 cadavers and saw different pathways. They observed that it crossed the level of the inguinal ligament just superficial to the ASIS in 29%, lateral to ASIS in 11% and medial to ASIS in 69%. Osterhoff et al. [38] observed that the LFCN is found to run 13.49 mm from lateral end of bar. Thus, a very short lateral end of the bar prevents the irritation of LFCN. However, we observed that the incidence of LFCN injury remains as high as up to 30% and thus proper identification of the nerve by careful dissection up to the bone and extending the incision as per comfort is important to minimize its occurrence. We also noticed that non-Asians were more susceptible to LFCN injury (40.9% versus 18.9% in Asians) and this could be because of anatomical variations.

HO though common is usually asymptomatic. Vaidya et al. in their study [19] found older age and higher injury severity score as risk factors for developing HO. However, no significant relation was found with sex, race, Majeed score and Glasgow coma scale in their study. This can be usually removed at the time of implant removal in cases of excessive bone formation. In our pooled analysis we observed a higher incidence of HO in non-Asian population and this could be related to the genetics as incidence of HO is known to be influenced by race [39]. HO was usually Grade 1 or 2 and no active intervention was required.

Femoral nerve palsy has also been reported as a rare complication. Hesse et al. [40] in their study reported 8 femoral nerve palsies in 6 patients. They said that injury is likely due to limited space available for the psoas muscle and femoral nerve and that sinking screws or under contouring of the rod is a possible cause of compression. Thus studies by Scherer et al. [41] recommended bar to bone distance of 20–25 mm to avoid compression. Vaidya et al. [23] recommended the screw head to be kept at the level of the sartorius such that the subcutaneous bar remains above the level of deep fascia.

Smith et al. [42] reported a case of bilateral compression of the external iliac artery after the application of INFIX. They identified on CT angiogram the bulging of the rectus muscle underneath the INFIX and subsequent compression against the bar which resolved by increasing the arc of

**Table 6** Complications

S. no.	Author	Non-union	Infection	Loosening	HO	LFCN	DVT	Femoral nerve injury	Loss of reduction	Early removal
1	Du [9]	–	1	–	–	–	2	–	–	–
2	Steer [10]	–	2	1	5	13	4	–	–	2
3	Liu [11]	–	–	–	–	–	–	–	–	–
4	Liu [11]	–	–	–	–	2	–	–	–	–
5	Yin [12]	–	1	–	12	10	–	–	–	–
6	Hua [13]	–	–	–	–	2	–	–	–	–
7	Ding [14]	–	–	–	–	4	–	1	–	–
8	Ding [14]	–	–	–	–	4	–	–	–	–
9	Shetty [15]	–	1	1	–	1	–	–	2	–
10	Wu [16]	–	–	–	8	3	–	1	–	–
11	Wang [17]	–	–	–	–	2	–	–	–	–
12	Fang [18]	–	1	2	–	14	–	1	–	5
13	Vaidya [19]	–	3	–	56	7	–	–	1	3
14	Vaidya [20]	–	–	–	–	2	–	–	–	–
15	Hoskins [21]	–	3	–	14	20	2	–	–	2
16	Muller [22]	–1	2	1	9	6	–	–	–	1
17	Vaidya [23]	–	3	–	32	27	–	–	3	6
18	Gardner [24]	–	1	–	6	2	–	–	–	–
19	Vaidya [25]	–	1	–	11	1	–	–	–	–
20	Zhang [26]	–	–	–	–	19	–	–	–	–
21	Kuttner [27]	–	1	1	–	7	–	–	–	1
22	Bi [28]	–	–	–	–	3	–	1	–	–
23	Dahill [29]	1	1	–	–	26	–	–	1	–
24	Wang [30]	–	–	1	–	4	–	2	–	1

HO heterotopic ossification, LFCN lateral femoral cutaneous nerve, DVT deep vein thrombosis

curvature. Merriman et al. [43] calculated average bar to vessel distance of 2.2 cm and rod to bladder distance of 2.6 cm. Thus, it can be usually avoided by proper implant placement and adequate contouring of the anterior bar.

Surgical site infection was seen in 17 cases (2.3%) with no evidence of osteomyelitis. Pelvic INFIX is seen to be associated with low rates of infection and is a safe procedure.

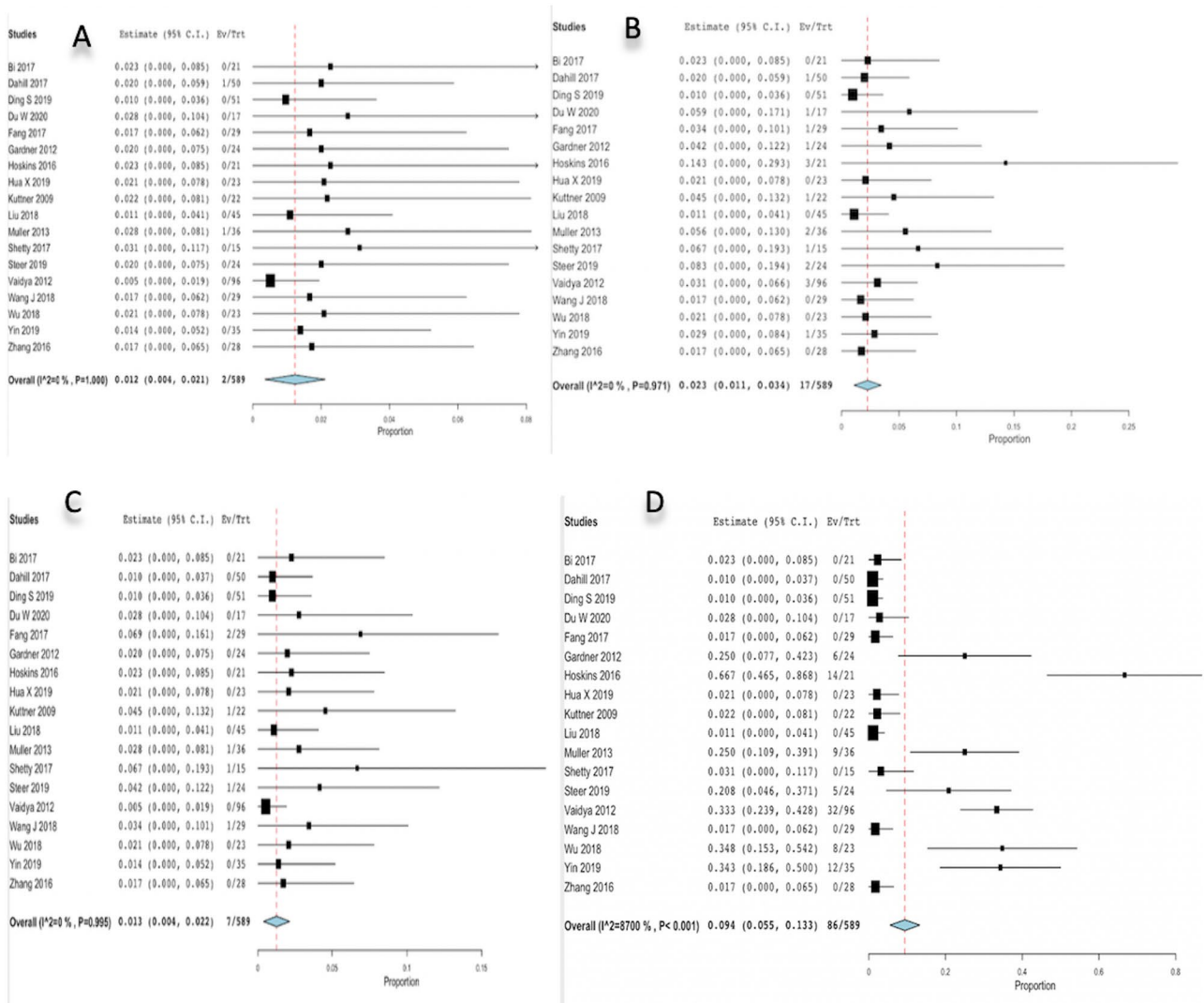
The rates of DVT have been seen to be low with the application of INFIX (1.2%). This may be due to early mobilization with this implant and the routine use of thromboprophylaxis.

There is an inherent risk of abdominal wall perforation with errant rod placement. It is important to maintain the rod in a subcutaneous position without violation of the abdominal fascia. This can be performed reliably by tunneling a path below the abdominal wall before rod insertion. Jain et al. [44] reported a rare case of bladder incarceration following application of INFIX in a case of pubic diastasis. This occurred at the time of compression of the diastasis after application of INFIX. Thus, an index of suspicion is

warranted and timely INFIX removal with open reduction and stabilization is warranted.

Patients with INFIX have “awareness” about their implants due to its subcutaneous position which is a cause of uneasiness as compared to conventional plating [39]. Thus, most of the implants require removal after radiological union. However, as opposed to an external fixator, the subcutaneous nature of this construct requires removal in an operating room.

Some modifications have been applied to INFIX technique with time. Few studies such as Bi et al. [28] and Wu et al. [16] have added a 3 cm Pfannenstiel incision 2 cm above the pubic symphysis and inserted a polyaxial pedicle screw through the ipsilateral or contralateral pubic tubercle to the inferior ramus. They believe that it forms a stable geometric triangle allowing better fit of the rod with the anatomy of the anterior pelvic ring. It also helps in better restriction of relative micro-movement between the sites of the fractured pubis. Wang et al. [30] used the modified INFIX technique for cases of pubic diastasis by inserting 4



**Fig. 4** Forest plots of comparison of **a** non-union, **b** infection, **c** implant loosening, **d** heterotopic ossification

screws (one each in pubic tubercle) in a series of 29 cases and reported excellent to good outcomes in 27 patients. Robot-assisted placement of screws has also been reported by Du et al. [9] and Liu et al. [11]. Liu et al. in their study compared robot-assisted INFIX with the conventional technique and showed shorter duration of surgery, need for lesser fluoroscopy, and reduced blood loss with the robotic technique.

There are some limitations in this study. The included studies as mentioned are all case series or comparative studies with no randomized control trial. There were only 3 studies available for comparative meta-analysis.

Secondly, a high statistical heterogeneity was noted for some of the outcomes reported in our analysis. We have, however, performed meta-regression and subgroup analysis to try and identify the reasons for heterogeneity.

From our systematic review and meta-analysis, it appears that INFIX is a valuable tool for reduction and fixation in unstable pelvic ring fractures and is well tolerated by the patient, allowing good mobility with acceptable complications and outcomes. It is a minimally invasive technique with less blood loss and surgical time in comparison with conventional plating with comparable complications and similar outcomes.

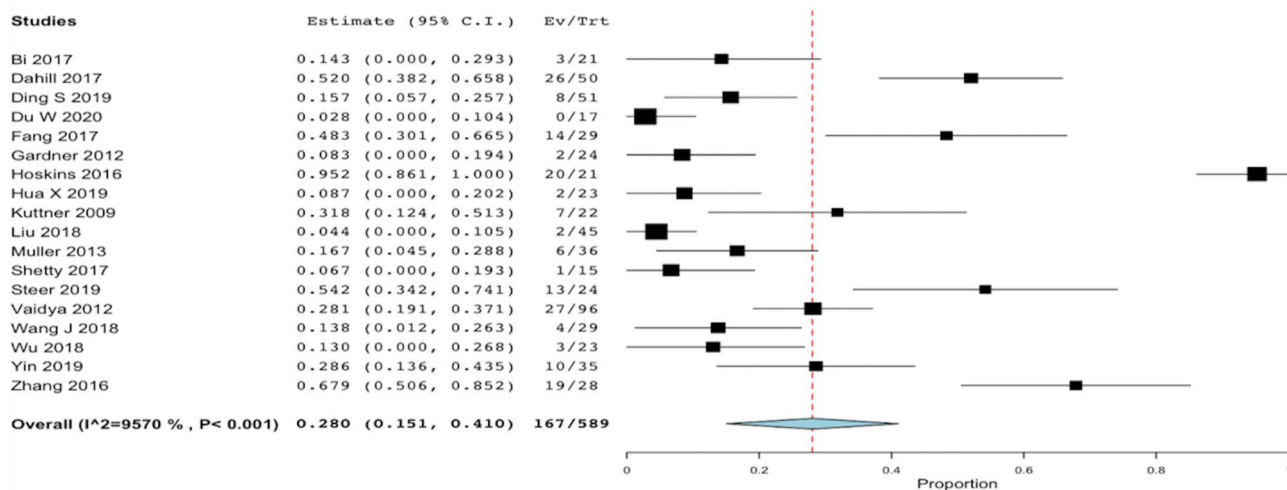


Fig. 5 Forest plot of comparison of LFCN injury in various studies

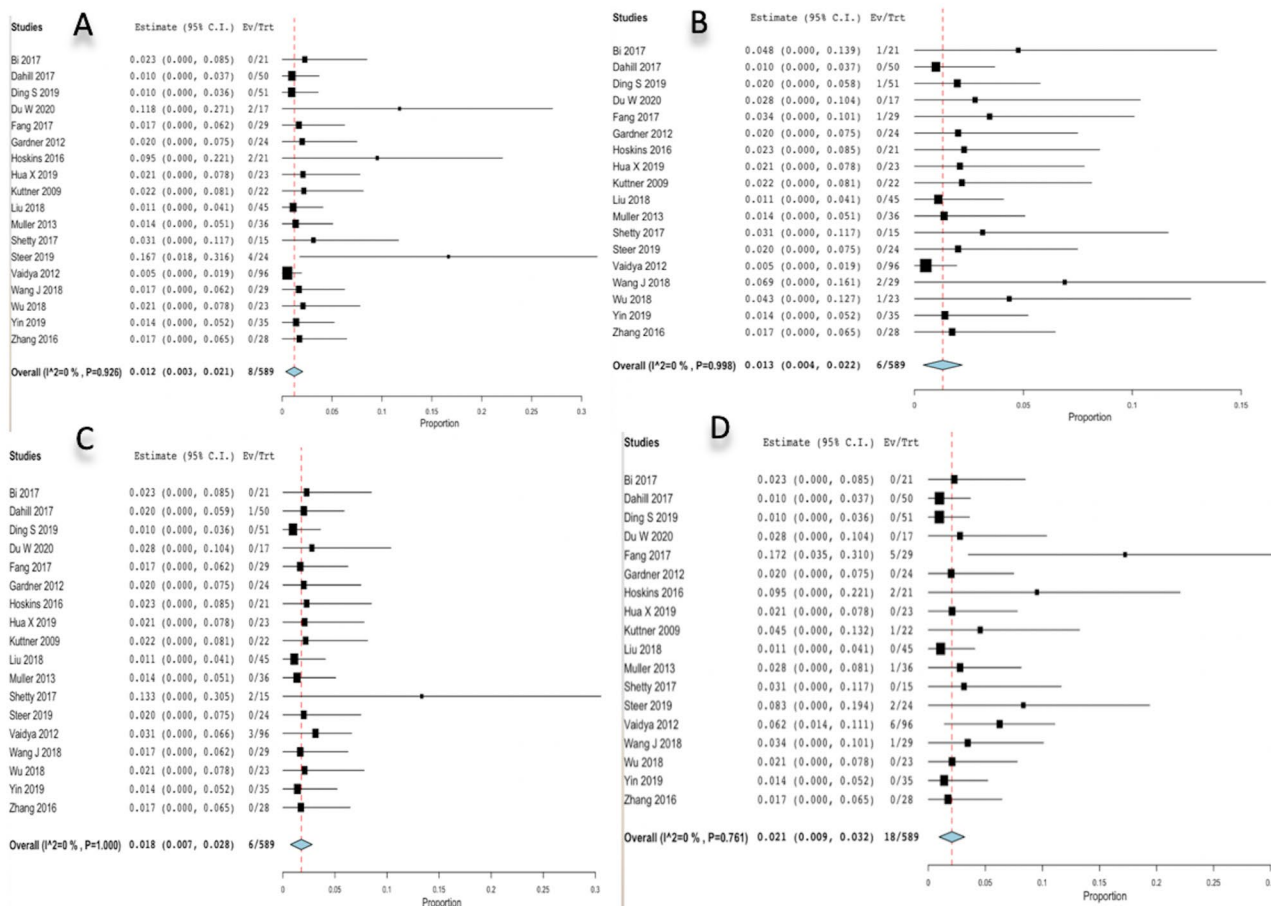


Fig. 6 Forest plots of comparison of a DVT, b femoral nerve injury, c loss of reduction, d early implant removal

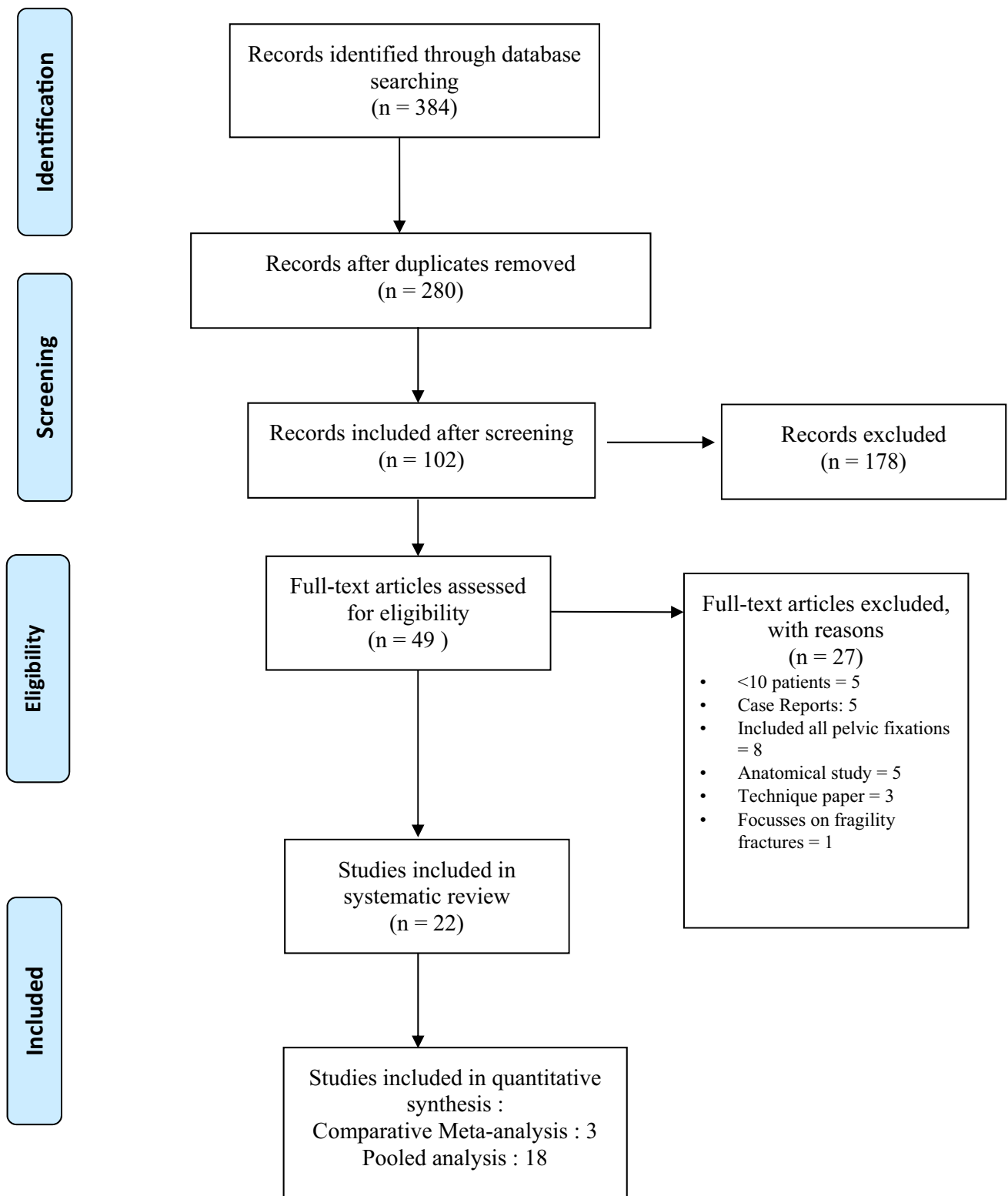


Fig. 7 PRISMA flow diagram for the study

## Conclusion

INFIX is a biomechanically stable and effective minimally invasive surgical technique for management of unstable pelvic ring fractures. However, it is imperative to stabilize the posterior ring first if required with use of plates and screws.

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## Compliance with ethical standards

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

**Ethical approval** This article does not contain any studies with human participants or animals performed by any of the authors.

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## Affiliations

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