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RESEARCH

Accuracy in navigated percutaneous sacroiliac screw fixation: a systematic review and meta-analysis

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Abstract

Introduction Percutaneous sacroiliac screw fixation of pelvic fragility fractures is increasingly being used to maintain mobility and reduce pain in the elderly patient population. Traditionally, this is performed using 2D fluoroscopy. Several newer, navigated techniques have emerged that may further facilitate this procedure. It, however, remains unclear whether there is a benefit regarding accuracy, radiation exposure and complications of these new navigation techniques when compared to the traditional 2D fluoroscopy.

Methods A systematic review and meta-analysis were performed. PubMed, CENTRAL and Embase were searched for both randomized controlled trials and observational studies comparing new navigation techniques to 2D fluoroscopy for percutaneous sacroiliac screw fixation. Effect estimates were pooled (random effects) and presented as odds ratio, mean difference and standardized mean difference with a 95% confidence interval.

Results 19 studies were included. The 2D fluoroscopy group had 642 patients and the new navigation group 663 patients. Accuracy was significantly higher in the new navigation group (OR 2.44, 95% CI 1.53–3.90), especially O-Arm, 3D CT and Robotic navigation. On average, accuracy was 82% in the 2D group and 92% in the new navigation group, which was significant. Also, fluoroscopy time (MD 71.89 s, 95% CI 51.37–92.41) and frequency (MD 17.22 images in total, 95% CI 7.73–26.70) were significantly reduced in the new navigation group. Complications are acceptably low, however, poorly reported in both groups.

Conclusion This meta-analysis demonstrated a higher accuracy, lower fluoroscopic frequency and time for new navigation techniques compared to 2D fluoroscopy. More advanced navigation techniques, such as 3D CT and robotic navigation, appeared to be even better.

Keywords Sacroiliac screws, Accuracy, Navigation, Radiation

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Introduction

The incidence of fragility fractures of the pelvis (FFP) is expected to rise due to an aging population, especially among women [1]. These fractures tend to cause significant pain negatively impacting the mobility in an already frail patient population [2–4]. To maintain mobility and independence as well as to reduce subsequent healthcare issues, such as decubitus and infections, there is a tendency towards operative treatment of FFP [5, 6].

The percutaneous sacroiliac screw fixation using intra-operative 2D fluoroscopic control was first described in 1997 [7]. Since then, it has evolved drastically. First, navigation based on 2D or 3D fluoroscopes was introduced [8]. Later, intra-operative CT-scans and O-arms became available to navigate and control reduction and screw positioning [9, 10]. Moreover, since the introduction of robotic surgery, active navigation using these robots is gaining popularity making the procedure even more time efficient while improving safety at the same time [11, 12].

Due to the relative novelty of all these techniques, only small series are available in literature. These studies mostly focused on complications and postoperative results. As complications are mostly related to screw misplacement, accuracy is the most relevant outcome and predictor of complications. Also, radiation exposure is often neglected in previous literature. 2D fluoroscopy in the pelvic area is challenging due to overlay of bowel gas [13]. Every attempt in reducing radiation exposure is relevant for both the patient and the surgical team and should be a priority. Therefore, the main goal of introducing a new technique should aim for improving accuracy and reducing radiation exposure. We hypothesize that new navigation techniques will lead to improved accuracy and reduced radiation exposure. We aimed to compare percutaneous sacroiliac screw fixation using 2D fluoroscopy (2DF) with new navigation techniques (NNT).

Methods

This meta-analysis was written according to the Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) checklist. This meta-analysis was registered at PROSPERO with the following ID CRD42023467321. No ethical approval was required.

Search strategy and selection criteria

We performed a search of electronic databases (PubMed, CENTRAL, Embase) for studies on percutaneous sacroiliac screw fixation. The search was performed on the 10th of April 2024. The search terms used were *sacroiliac* OR *iliosacral* AND *fluoroscopy*.

All randomized controlled trials and observational studies that compared traditional percutaneous sacroiliac screw fixation using 2D fluoroscopy to new navigation techniques, were considered for inclusion. ***New navigation techniques*** included 2D fluoroscopic navigation, computer assisted ultrasound navigation, 3D fluoroscopic navigation with a C-arm, 3D navigation with an intraoperative mobile CT, 3D navigation with an intraoperative O-Arm or robotic. With regular 2D fluoroscopic the surgeon determines the screw trajectory free hand based on pelvic inlet, outlet, anteroposterior and lateral views. A brief description of the new navigation techniques is found in supplement 1.

Inclusion criteria were all pelvic injuries (high- and low-energy trauma) and reporting on the outcomes of interest. Exclusion criteria were in vitro studies, percutaneous screw fixation of other parts of the pelvis than the sacroiliac joint, languages other than English, Dutch or German, no availability of full-text, and letters to the editor.

Data collection

Two reviewers (RAH and BJMW) independently screened the title and abstract for eligibility. In case of disagreement, this was solved by a third reviewer (BCL). A cross-check of the references from the original studies was performed to identify potential additional papers.

The following baseline characteristics were collected: first author, year of publication, country of publication, study design, number of included patients and number of screws implanted.

Outcomes

The primary outcome of interest was accuracy. Accuracy was defined as correct and intraosseous positioning of the screw without interference with the neuroforamina [14–17]. This simplified definition was chosen to fit the multitude of classification systems for screw mal-positioning in included studies. Accuracy was described as a percentage.

Secondary outcomes were radiation exposure, surgery duration and complications. Complications included screw revision, pain related to malpositioning, loosening of the screw, sensory disturbances, infection, cement leakage or restricted movement. Radiation exposure was measured in either fluoroscopy time (seconds), fluoroscopy frequency (number of images) or radiation dose (mGy or Gy/cm^2).

Quality assessment

The two previously mentioned reviewers (RAH and BJMW) independently assessed the methodological quality of the studies included according to the MINORS criteria. Details are described in the supplementary material Table 2.

Statistical analysis

Continuous variables were presented as weighted means based on the study population size with standard deviation (SD) or information was converted to mean and SD using the methods described in the Cochrane Handbook for Systematic Reviews of Interventions [18]. If variables reported different outcome units, these were standardized. Dichotomous variables were presented as counts and percentages. Effects were pooled using the (random effects) Mantel-Haenszel method and presented as odds ratio (OR), mean difference (MD) and standardized mean difference (SMD) each with a 95% confidence interval (95% CI). Heterogeneity between studies was assessed by visual inspection of forest plots and by the I^2 statistic for heterogeneity. A p-value below 0.05 was considered statistically relevant. Review Manager (RevMan, version 5.4) was used for all statistical analysis. All statistical analyses were performed separately for in vivo and in vitro studies.

Sensitivity analysis

A sensitivity analysis was performed on the primary outcome for study quality. High and moderate quality studies were defined as studies with a MINOR score higher than 15 points and low quality studies were defined as studies with a MINOR score lower than 15 points.

Results

Literature search

Figure 1. shows a detailed description of the literature search and study selection. In total 19 articles were included [8–12, 19–32]. 16 studies were observational studies, whereas three studies were randomized clinical trials.

Quality assessment

The MINORS scores are described in supplementary material Table 3. 13 studies were of poor quality and 6 studies of moderate to high quality. All studies were assessed in terms of risk of bias. The graph and summary are provided in supplementary material 5.

Baseline characteristics

There were six different new navigation techniques. Six studies used 3D CT scans, four robot navigation, four 3D fluoroscopy, two O-arm scans, two studies 2D navigation and one study computer assisted ultrasound. In total, 1205 patients were included; 642 patients were treated with the conventional 2D technique and 663 patients with a new navigation technique. In total 657 screws were placed in the conventional 2D group and 741 screws in the new navigation group. Four studies did not report on the number of screws. All baseline characteristics of the studies are described in Table 1.

Primary outcome

Accuracy

Accuracy was reported in 14 studies. More screws were positioned correctly in the new navigation group (OR 2.44, 95% CI 1.53–3.90, I^2 0%, $p < 0.00001$). On average 82% were positioned correctly in the 2D group versus 92% in the new navigation group (MD 0.10, 95%CI 0.06–0.14, I^2 0%, $p = 0.0004$). (Fig. 2).

Secondary outcomes

Radiation exposure

Ten studies reported the total fluoroscopy time. This was significantly shorter with the use of new navigation techniques in all studies without any exception (MD 71.89 s, 95% CI 51.37–92.41, I^2 95%, $p < 0.00001$) (Fig. 3).

Three other studies reported fluoroscopy frequency instead of time. Fluoroscopy frequency also was less with the use of a new navigation technique (MD 17.22 images in total, 95% CI 7.73–26.70, I^2 97%, $p = 0.0004$) (Fig. 4).

Measured radiation dose, however, was not significantly different (SMD 0.46, 95% CI 0.03–0.89, I^2 82%, $p = 0.04$) (Fig. 5). All new navigation techniques, except robot navigation and CAS ultrasound were represented.

Surgery duration

Surgery duration was reported in 11 studies and showed no significant difference (MD 8.07 min, 95% CI −4.65–20.79, I^2 99%, $p = 0.21$) (Fig. 6).

Complications

Only six studies reported postoperative complications. An overview is presented in Table 2. Of those six studies, follow-up time was available for only three studies. One study (Privalov et al.) mentioned one complication in the 2D fluoroscopy group, which was not further specified. Berger-Groch et al. revised all patients with screw loosening. Madeja et al. found that all patients with screw loosening were asymptomatic. The one infection mentioned by Boudissa et al. was a surgical site infection and was surgically revised. Madeja et al. reported on five infections in total, which were all superficial. It is not known if revision surgery was necessary. Pain or sensory disturbances were not further specified in most studies. Tonetti et al. found seven patients with a lesion of the lumbosacral trunk, five patients with an S1 root lesion and six patients with a cauda equina lesion. However, eight lesions were preexisting. Restricted movement was defined as restricted squatting or limping. It is not known if implant removal or revision surgery was performed on those patients.

Sensitivity analysis

Six studies of high quality were available. Four of those studies reported on the primary outcome. A sensitivity

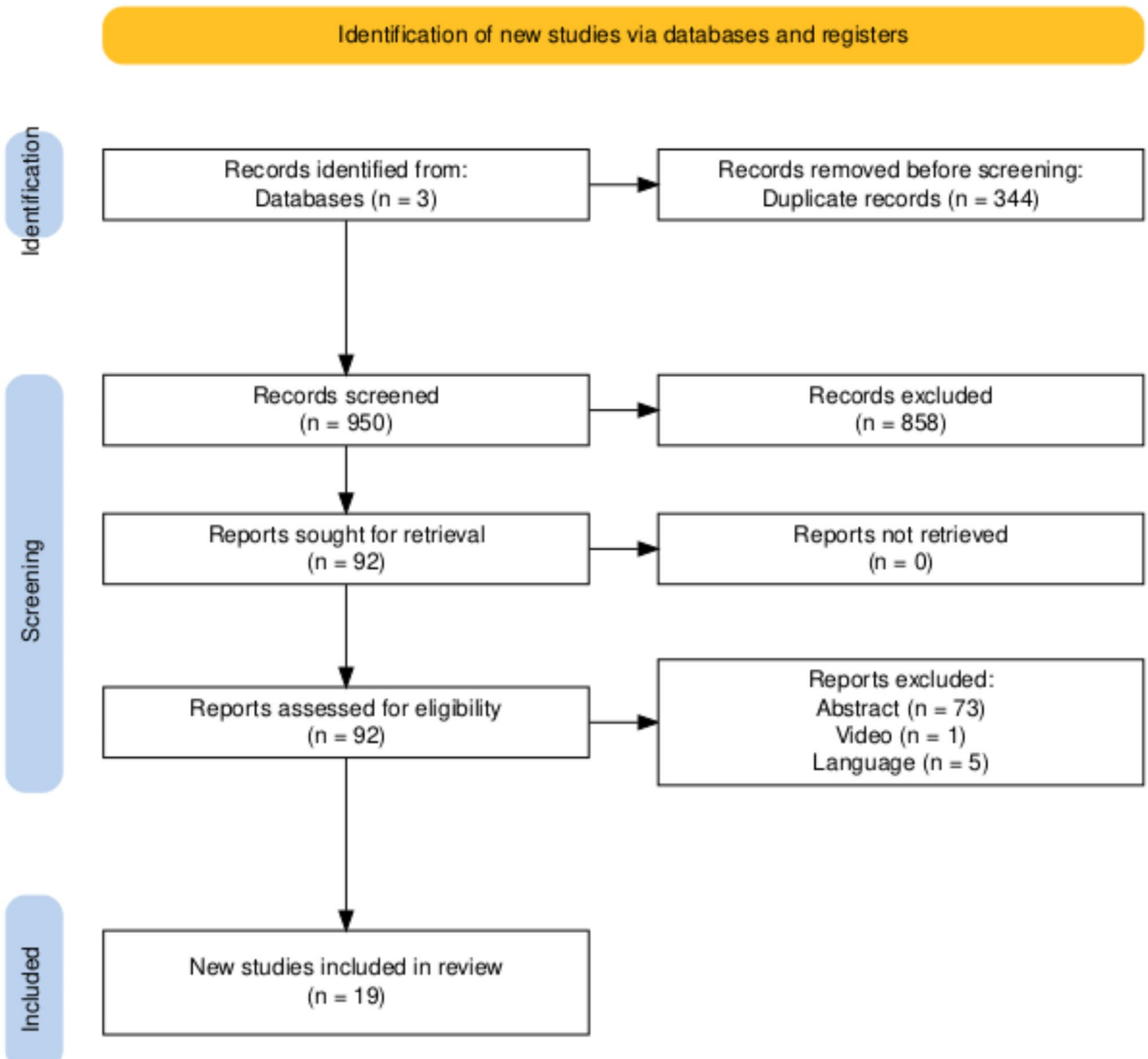

Fig. 1 Flow diagram of search and study selection

analysis of those four studies compared to low quality studies showed no difference ($p = 0.14$). Furthermore, a sensitivity analysis based on study design was performed. This also showed no difference ($p = 0.82$) (supplementary material 5).

Discussion

This meta-analysis comparing 2D fluoroscopy to new navigation techniques for percutaneous sacroiliac screw fixation included 19 studies with in total 1205 patients and demonstrated a higher accuracy, lower fluoroscopy usage (as defined by the number of intraoperative images) and reduced fluoroscopy time for new navigation techniques. Notably, the amount of radiation exposure (measured in mGy or Gy/cm^2) was higher for the new navigation techniques. No difference in surgical duration was detected. Complications were rare for both techniques.

Comparison to previous literature

To date no meta-analysis on percutaneous sacroiliac screw placement has been published comparing 2D versus new navigation techniques combined. One systematic review was performed comparing both techniques in patients with pelvic fractures in general [33]. Notably, their study population also included patients who underwent open surgical procedures including plate fixation and the use of intra-operative 3D templates as implant

Table 1 Baseline characteristics in vivo studies

Author	Year	Country	Study design	*N*		New navigation technique	Screws	
				2D	New		2D	New
Berger-Groch et al.	2018	Germany	Retrospective cohort	36	100	3D fluoroscopy	62	170
Boudissa et al.	2022	France	Retrospective cohort	97	30	3D CT	129	45
Han et al.	2021	China	Retrospective cohort	25	38	Robot	35	54
Kraus et al.	2010	Germany	Retrospective cohort	2	20	3D fluoroscopy	62	170
Kulakowski et al.	2022	Poland	Retrospective cohort	36	37	3D fluoroscopy	57	56
Long et al.	2019	China	Prospective cohort	56	35	Robot	43	66
Li et al.	2015	China	Retrospective cohort	43	38	3D CT	29	35
Li et al.	2023	China	Retrospective cohort	30	27	Robot	42	54
Lu et al.	2020	China	Retrospective cohort	21	19	O-arm	23	22
Madeja et al.	2022	Czech Republic	Retrospective cohort	97	30	2D navigation	35	39
Matityahu et al.	2014	USA/Germany	RCT	54	58	3D CT	NR	NR
Passias et al.	2020	USA	Retrospective cohort	105	28	O-arm	NR	NR
Peng et al.	2020	China	RCT	15	13	2D navigation	NR	NR
Privalov et al.	2020	Germany	Retrospective cohort	4	25	3D CT	NR	NR
Prost et al.	2024	Germany	Retrospective cohort	46	22	3D CT	55	30
Tonetti et al.	2010	France	Retrospective cohort	30	4	Computer assisted ultrasound	51	10
Verbeek et al.	2016	Netherlands	Retrospective cohort	24	56	3D fluoroscopy	39	111
Wang et al.	2017	China	RCT	15	15	Robot	22	23
Zwingmann et al.	2009	Germany	Prospective cohort	32	24	3D CT	35	26

positioning tool. Our meta-analysis did not include the use of these 3D templates as these are costly, require an open approach and take long preparation times. The authors found similar results regarding accuracy (125 s versus 74 s).

Three systematic reviews, on one navigation technique comparing to 2D fluoroscopy, have been published. Contrary to our study, no meta-analysis on different navigation techniques has been performed [34–36]. Two systematic reviews compared robot assisted surgery to 2D fluoroscopy, while another compared 3D fluoroscopy with 2D fluoroscopy. In alignment with our findings, the advantages of navigation were more pronounced in studies evaluating robot assisted surgery, suggesting that more advanced navigation techniques contribute to improved outcomes compared to the less advanced 3D fluoroscopy technique.

Furthermore, six in vitro studies support these findings [37–42]. Accuracy was higher and fluoroscopy frequency was lower with new navigation techniques. Surgery duration is not representable in in vitro studies, due to a non-clinical setting.

Interpretation of results

Accuracy appears to be considerably higher for the new navigation techniques, as shown by an absolute difference of 10% (95% CI 6%-14%) with little heterogeneity (I2 = 0%). It is important to consider several aspects.

Firstly, the meta-analysis shows that new navigation techniques have advantages in some aspects compared to conventional 2D fluoroscopy. This could be explained by the ease of use and precision of imaging. The ability of tailored workflows could also be contributive to especially lower fluoroscopy frequency and usage as well as lower surgery duration. An attempt was made to investigate the performance of each navigated technique individually. This showed that certain navigation techniques (O-ring, 3D CT, robot) seem to be better than other navigation techniques (2D navigation, computer assisted ultrasonography, 3D fluoroscopy) when compared to 2D fluoroscopy. This finding however does not necessarily imply that O-ring, 3D CT or robot will perform better in a direct comparison with 2D navigation, computer assisted ultrasound or 3D fluoroscopy. The magnitude of the beneficial effect on accuracy is also dependent on the control group. It might very well be possible that in the studies on O-ring, 3D CT and robot, the accuracy in the control group was low giving the impression that these techniques are extremely good.

Secondly, and in extension to the previous consideration, accuracy is also dependent on experience. It was not possible to account for this in the analysis. Thus, we are uncertain to what degree experience played a role in our findings on accuracy. The same also applies for the secondary outcomes.

Radiation exposure, as measured in time and frequency, also seems lower for the new navigation techniques. Although there were high levels of heterogeneity in this analysis, all individual studies found the new navigation techniques to be superior. In other words, heterogeneity mostly occurred in the magnitude, not the direction of this finding. This indicates that the new

Study or Subgroup	2D fluoroscopy Events	2D fluoroscopy Total	New navigation technique Events	New navigation technique Total	Weight	Risk Difference M-H, Random, 95% CI
1.2.1 2D navigation						
Peng et al.	1	15	1	13	3.8%	−0.01 [−0.20, 0.18]
Subtotal (95% CI)		15		13	3.8%	−0.01 [−0.20, 0.18]
Total events	1		1			
Heterogeneity: Not applicable						
Test for overall effect: Z = 0.10 (P = 0.92)						
1.2.2 Computer assisted ultrasound						
Tonetti et al.	11	30	1	4	0.7%	0.12 [−0.34, 0.57]
Subtotal (95% CI)		30		4	0.7%	0.12 [−0.34, 0.57]
Total events	11		1			
Heterogeneity: Not applicable						
Test for overall effect: Z = 0.50 (P = 0.62)						
1.2.3 3D fluoroscopy						
Berger–Groch et al.	8	36	14	100	6.1%	0.08 [−0.07, 0.23]
Kulakowski et al.	4	36	3	37	7.8%	0.03 [−0.11, 0.17]
Verbeek et al.	4	24	10	56	4.4%	−0.01 [−0.19, 0.17]
Subtotal (95% CI)		96		193	18.3%	0.04 [−0.05, 0.13]
Total events	16		27			
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.64$, df = 2 (P = 0.73); $I^2 = 0\%$						
Test for overall effect: Z = 0.83 (P = 0.40)						
1.2.4 O-arm						
Lu et al.	5	21	1	19	3.3%	0.19 [−0.02, 0.39]
Prost et al.	5	46	0	22	11.8%	0.11 [−0.00, 0.22]
Subtotal (95% CI)		67		41	15.1%	0.13 [0.03, 0.22]
Total events	10		1			
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.49$, df = 1 (P = 0.48); $I^2 = 0\%$						
Test for overall effect: Z = 2.54 (P = 0.01)						
1.2.5 3D CT						
Boudissa et al.	8	97	1	30	19.9%	0.05 [−0.04, 0.13]
Li et al.	6	43	1	38	10.7%	0.11 [−0.00, 0.23]
Mattiyahu et al.	11	54	0	58	11.7%	0.20 [0.09, 0.31]
Zwingmann et al.	19	32	7	24	2.3%	0.30 [0.05, 0.55]
Subtotal (95% CI)		226		150	44.6%	0.14 [0.04, 0.25]
Total events	44		9			
Heterogeneity: $Tau^2 = 0.01$; $Chi^2 = 8.76$, df = 3 (P = 0.03); $I^2 = 66\%$						
Test for overall effect: Z = 2.63 (P = 0.008)						
1.2.6 Robot						
Han et al.	3	25	0	38	7.7%	0.12 [−0.02, 0.26]
Li et al	6	30	2	27	4.7%	0.13 [−0.05, 0.30]
Wang et al.	1	15	0	15	5.1%	0.07 [−0.10, 0.23]
Subtotal (95% CI)		70		80	17.5%	0.11 [0.02, 0.20]
Total events	10		2			
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.32$, df = 2 (P = 0.85); $I^2 = 0\%$						
Test for overall effect: Z = 2.31 (P = 0.02)						
Total (95% CI)		504		481	100.0%	0.10 [0.06, 0.14]
Total events	92		41			
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 12.54$, df = 13 (P = 0.48); $I^2 = 0\%$						
Test for overall effect: Z = 5.07 (P < 0.00001)						
Test for subgroup differences: $Chi^2 = 3.97$, df = 5 (P = 0.55), $I^2 = 0\%$						

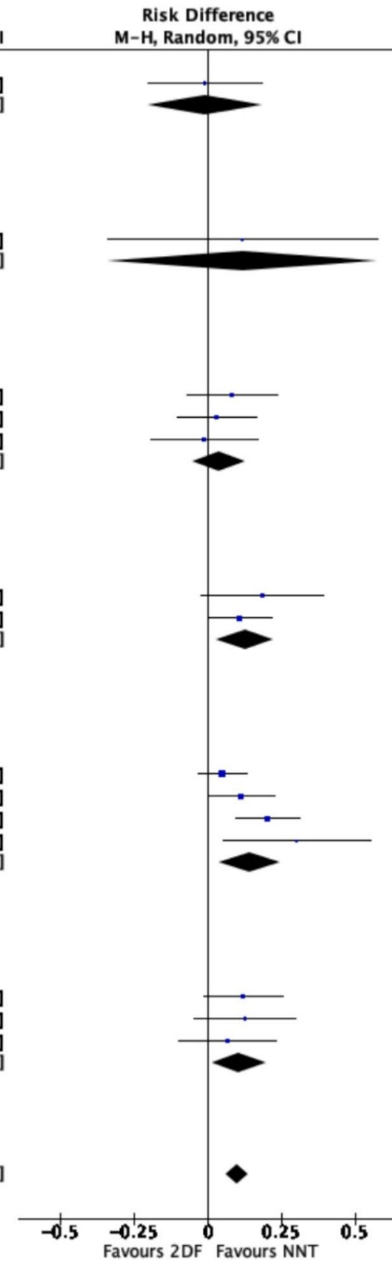

Fig. 2 Forrestplot accuracy

navigation techniques are better. To what extent, however, is difficult to say.

Notably, radiation exposure as measured in radiation dose, was higher in the new navigation techniques. This may be tempered by the fact that all patients in the 2D group received a postoperative CT scan to check for correct placement, which is obsolete in the new navigation techniques. This additional radiation exposure was not accounted for in the analysis. In general, a pelvic CT accounts for a radiation exposure of 14 mSv. 14 mSv is the dose produced by exposure to 14 mGy of radiation [43]. Therefore, it is imaginable that borderline significant difference would not be significant if the postoperative CT scan was added.

Finally, it should be acknowledged that implementation costs of new navigation techniques are high. The technology needs to be purchased, the operating theater adopted to accommodate the new technology and staff trained, driving the costs even further up. Indeed, new navigation techniques reduce the need for revision surgery by improving accuracy. Whether the reduction in costs for revision surgery outweighs the implementation costs of a new technique remains to be seen.

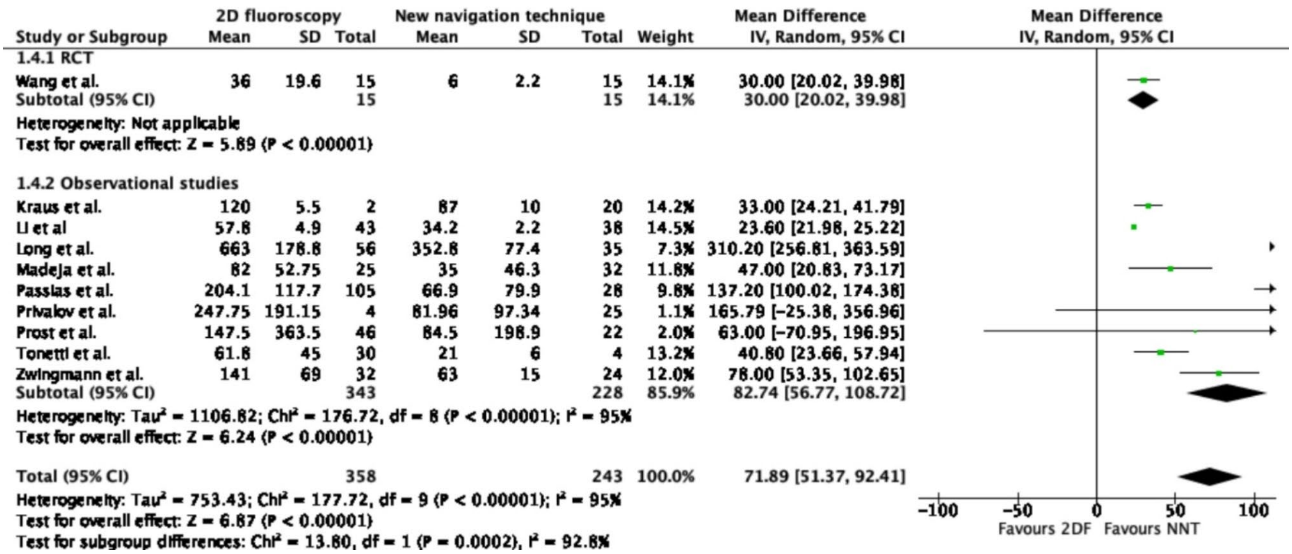

Fig. 3 Forrestplot fluoroscopy time

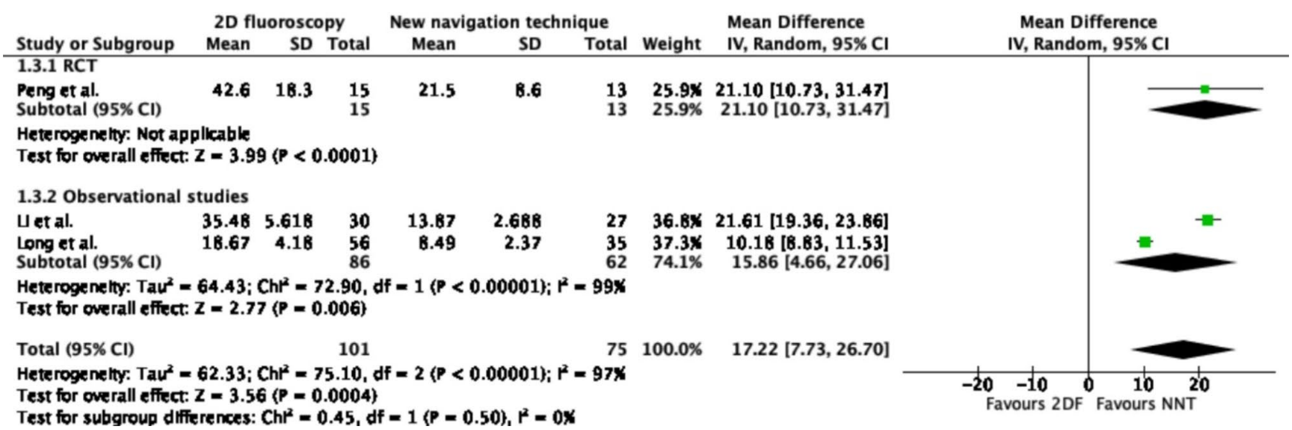

Fig. 4 Forrestplot fluoroscopy frequency

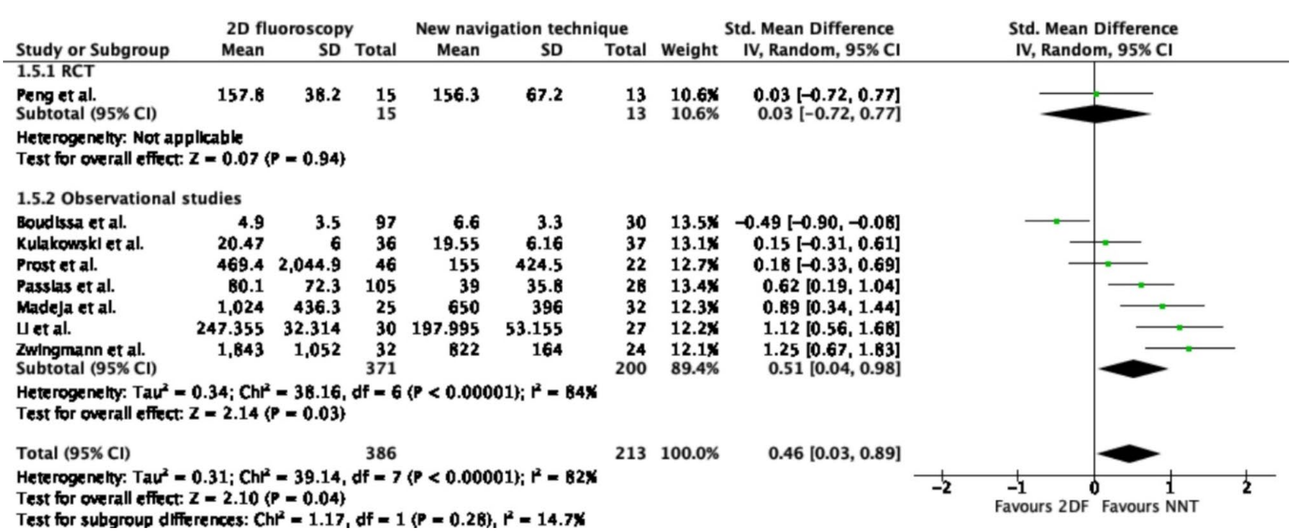

Fig. 5 Forrestplot radiation dose

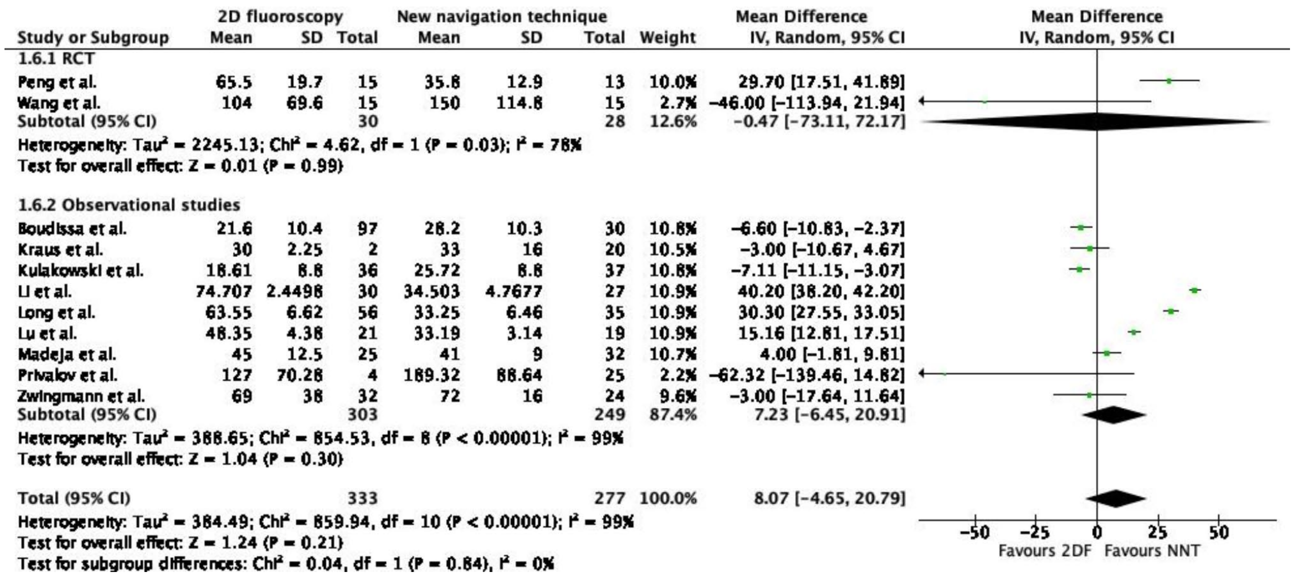

Fig. 6 Forrestplot surgery duration

Table 2 Overview of complications

Author (2D/new)	Complication						
	Screw revision (2D/new)	Pain (2D/new)	Screw loosening (2D/new)	Sensory disturbance (2D/new)	Infection (2D/new)	Cement leakage (2D/new)	Restricted movement (2D/new)
Berger-Groch (36/100)	7/9	2/3	2/3	1/1	NR	NR	NR
Boudissa (97/30)	NR	NR	NR	2/1	1/0	0/1	NR
Madeja (97/30)	NR	NR	4/3	NR	2/3	NR	NR
Peng (15/13)	NR	1/1	NR	NR	0/0	NR	4/3
Tonetti (30/4)	NR	NR	3/1	10/0	NR	NR	NR
Verbeek (24/56)	0/5	NR	NR	7 in total	NR	NR	NR
Total (299/233)	7/14	3/4	9/7	13/2	3/3	0/1	4/3

Limitations

Several limitations must be considered. As already described, there was considerable heterogeneity for the analysis on surgical duration. Experience of the surgical team was not described and could not be factored in. It is likely that experience with the new navigation technique or surgical experience in general especially leads to reduced surgical duration. But an influence on the other outcomes is conceivable. Furthermore, we would like to emphasize that the results of this meta-analysis are only applicable for new navigation techniques assorted. Which of the individual navigation techniques is.

better than the other remains to be defined. Lastly, this meta-analysis included both RCTs and observational studies. Although, there are increasing amounts of evidence suggesting that RCTs have the same value as observational studies in the surgical field, the overall quality for both RCTs and observational studies was moderate to poor. A sensitivity analysis between studies from high quality and low quality or between RCTs and observational studies did not show a significant difference.

Conclusion

This meta-analysis demonstrated a higher accuracy of screw positioning, lower fluoroscopic frequency and time for navigated percutaneous sacroiliac screw fixation compared to conventional 2D fluoroscopy. More advanced navigation techniques, such as 3D CT and robotic navigation, appeared to be even better than other new navigation techniques. Complications are acceptably low for both groups, however, data was limited. Future studies should focus on which of the new navigation techniques is the best and whether the implementation costs of a new technique outweigh its benefits.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12893-025-02813-z.

Supplementary Material 1

Supplementary Material 2

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Not applicable.

Author contributions
The authors RAH and BJMW performed the literature search. RAH wrote the manuscript. All authors have critically read, provided substantial revisions and approved of the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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