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The Impact of Fixation Sequence on Sacroiliac Screw Malposition in Combined Anterior-Posterior Pelvic Fixation: A Scoping Review

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Abstract

Unstable pelvic ring fractures often require combined anterior and posterior fixation. Percutaneous sacroiliac (SI) screw fixation is widely used for posterior stabilization but is technically demanding due to the narrow osseous corridors of the sacrum and the proximity of adjacent neurovascular structures. Reported malposition rates differ substantially by imaging modality, and the influence of fixation sequence (anterior-first vs posterior-first) on screw accuracy and clinical outcomes is not well characterized. This scoping review aims to evaluate the incidence and risk factors of SI screw malposition in combined anterior-posterior pelvic fixation and examines whether fixation sequence influences screw accuracy, reduction quality, or clinical outcomes. A scoping review was conducted in accordance with Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines. PubMed, Embase, and CENTRAL were searched from inception to April 17, 2026 for studies evaluating combined anterior and posterior pelvic fixation including percutaneous or closed sacroiliac/iliosacral screw fixation in predominantly adult patients with pelvic ring fractures. Studies were eligible if they reported SI screw malposition or related screw-accuracy, reduction quality, or clinical outcomes. Data synthesis was primarily descriptive and narrative due to anticipated heterogeneity in study design, definition of malposition, and imaging modalities. Of 365 records identified, 313 were screened after duplicate removal and 128 underwent full-text assessment, yielding 12 included studies (2003-2023; 716 patients, 436 with combined anterior-posterior pelvic fixation). Designs comprised 10 retrospective cohorts, one prospective case series, and one randomized controlled trial. Eight studies reported SI screw malposition with extractable data; patient-level rates ranged from 0% to 10.4%, with a descriptive crude aggregate of 10 of 265 patients (3.8%), or nine of 182 (4.9%) among patients confirmed to have combined fixation; these figures are presented for orientation only given marked heterogeneity in definitions, assessment methods, and denominators. Studies using three-dimensional intraoperative guidance (CT guidance or intraoperative 3D fluoroscopy) reported zero malpositions, whereas two-dimensional fluoroscopy studies reported rates up to 10.4%. Only one study tested candidate risk factors against screw position, and none was significantly associated with malposition. Six studies reported fixation sequence, but no study compared SI screw accuracy between anterior-first and posterior-first sequences. SI screw malpositioning is an important complication of posterior pelvic fixation, with a descriptive aggregate of 3.8% across studies. Risk factors for malposition remain inadequately studied, and no factor has yet been shown to be significantly associated with malposition; advanced 3D intraoperative imaging was associated with no detected malpositions in two included studies. The effect of fixation sequence remains unknown, and prospective multicenter studies using standardized malposition definitions and CT-based assessment are needed to clarify predictors of screw accuracy and optimize fixation technique.

Categories: Trauma, Radiology, Orthopedics
Keywords: ct-guided placement, fixation sequence, iliosacral screw, orthopaedic trauma, pelvic fixation, pelvic ring fracture, percutaneous fixation, sacroiliac screw, scoping review, screw malposition

Introduction And Background

Unstable pelvic ring fractures are high-energy injuries typically resulting from life-threatening external forces such as motor vehicle accidents or falls from significant heights. These injuries frequently require operative stabilization to restore pelvic architecture, permit early mobilization, and prevent long-term morbidities such as leg length discrepancy and genitourinary impairment [1-3]. Higher energy injuries tend to produce rotationally and vertically unstable patterns due to disruption of both the anterior and posterior components of the pelvic ring [4]. In these situations, anterior fixation is generally performed before posterior fixation because adequate reduction and fixation of the anterior ring often enhances the subsequent fixation and stability of the posterior ring [5]. Surgical options for anterior fixation are chosen based on the specific injury profile and physical condition of the patient. Open reduction and internal fixation (ORIF) via symphyseal plating is often considered the method of choice, allowing for rigid mechanical stability and direct visualization of the injury [6]. For a minimally invasive approach, anterograde or retrograde superior pubic ramus screws may be inserted under fluoroscopic guidance [7].

Anterior pelvic external fixation (APEF) may also be considered when concomitant severe peripelvic soft tissue or visceral injuries make internal fixation less desirable [8]. Once anterior fixation is established, percutaneous sacroiliac (SI) screw fixation is often regarded as the gold standard posterior stabilization technique for providing rigid stability while also minimizing blood loss and infection risk [9,10]. Other posterior fixation options include transsacral-transiliac screws for highly unstable patterns or vertically oriented sacral fractures and percutaneous reconstruction plates to decrease the risk of damaging adjacent nerves and blood vessels [11,12].

Despite the widespread adoption of percutaneous SI screw fixation, accurate screw placement remains technically demanding. The narrow osseous fixation pathways of the sacrum and the proximity of adjacent neurovascular structures create a narrow margin for error, and screw malposition can result in neurologic injury, vascular injury, or fixation failure [13]. Anatomic variation further complicates placement, as sacral dysmorphism in the form of reduced or absent S1 corridors has been reported in approximately 15% of the population, although more recent data suggests incidences as high as 53%. This requires alternative trajectories or S2 instrumentation [14-16]. Furthermore, other variations such as non-collinear S1 and S2 angles make it extremely difficult to achieve a single fluoroscopic view tangential to both segments, increasing the risk of misplacement [17]. Reported malposition rates reflect this technical challenge and vary substantially by imaging modality. A 2013 systematic review and meta-analysis of 51 studies and 2,353 percutaneous screws found pooled malposition rates of 2.6% with conventional fluoroscopy, 1.3% with 2D/3D image-based navigation, and 0.1% with CT navigation, and revision rates of 2.7%, 1.3%, and 0.8%, respectively [18]. However, newer reports have identified fluoroscopic malposition rates as high as 26%, further highlighting the variability in reported outcomes [19].

While the technical challenges of SI screw placement are well described in isolation, less attention has been paid to how the context of combined anterior-posterior fixation constructs may influence screw accuracy. The optimal sequence of fixation in combined anterior-posterior constructs (anterior-first vs posterior-first) is incompletely characterized in the published literature. Current surgical protocols vary, with some surgeons stabilizing the anterior ring first to facilitate posterior reduction, while others may perform posterior fixation first in the prone position before transitioning the patient to supine for anterior fixation [9,11,20]. To avoid the logistical challenges of repositioning, some surgeons also approach the sacroiliac joint from a supine position on a radiolucent table, inserting the iliosacral screws percutaneously [15]. While prioritization of the posterior ring is often favored due to its role as the main weight-bearing portion of the pelvis and determinant of chronic lower back pain, direct comparisons between sequences are limited, and the influence of fixation sequence on SI screw placement accuracy in combined constructs has not been well defined [6]. Additionally, although biomechanical evidence suggests that rigid posterior fixation alone may provide around 70%-85% of torsional and axial load resistance required to manage certain vertical shear injuries, clinical findings indicate that posterior fixation alone may not adequately control the anterior ring, leaving the hemipelvis prone to paradoxical rotational deformities and secondary displacement at the sacroiliac joint [8]. Because of its superior biomechanical stability compared to isolated posterior fixation, combined anterior and posterior internal fixation remains the generally recommended clinical standard [4].

Given these gaps in the literature, the purpose of this scoping review was to: (1) determine the incidence of SI screw malposition in patients undergoing combined anterior and posterior pelvic fixation, (2) identify patient, fracture, and technical factors associated with malposition, and (3) evaluate whether fixation sequence influences screw accuracy, reduction quality, or clinical outcomes.

Review

Methods

Search Strategy

This scoping review was performed in accordance with Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines [21]. A comprehensive search was conducted in PubMed, Embase, and CENTRAL from database inception to April 17, 2026, which was the final search date for all three databases. The search combined three concept blocks using the Boolean operator AND, with synonyms within each block combined using OR: pelvic fracture terms, sacroiliac/iliosacral screw terms, and screw-outcome terms. Free-text keywords were used. The full PubMed search strategy was: ((“pelvic ring fracture” OR pelvic fracture) AND (“sacroiliac screw” OR “iliosacral screw”) AND (malposition OR accuracy OR perforation OR complication)). The same keywords and Boolean structure were applied in Embase and CENTRAL. The full search strategies for Embase and CENTRAL are available from the corresponding author upon request. Studies were imported into Rayyan [22] for screening, duplicate removal, and full-text review.

Eligibility Criteria

Eligibility was defined according to the Population, Concept, and Context (PCC) framework [23] recommended for scoping reviews under JBI methodology [24] and PRISMA-ScR [21], rather than the PICOS framework used for systematic reviews of intervention effects. No review protocol was prospectively

registered or published; the eligibility criteria, data extraction items, and planned synthesis were defined by the authors before screening began. Eligible study designs included randomized controlled trials, cohort studies, case-control studies, and case series with at least 10 patients. Case reports, case series with fewer than 10 patients, narrative reviews, prior systematic reviews and meta-analyses, editorials, letters, cadaveric or biomechanical studies, and conference abstracts without full text were excluded. Only English-language studies with full text available were included.

Population: Eligible studies included adults (18 years or older), or predominantly adult cohorts in which a small number of adolescent patients could not be separated from the adult data (Ziran et al. [20] and Moussa et al. [4]), with pelvic ring fractures treated with combined anterior and posterior fixation, including open or closed iliosacral/SI screw fixation. Studies that had subgroups of patients that had combined anterior and posterior fixation that had extractable outcomes were also included. Studies of isolated anterior fixation, isolated posterior fixation, external fixation alone, or constructs that did not include SI screws were excluded.

Concept: The review examined the incidence and risk factors of sacroiliac screw malposition in patients undergoing combined anterior and posterior pelvic fixation, and whether fixation sequence (anterior-first vs posterior-first) influences screw placement accuracy, reduction quality, and clinical outcomes; identifying gaps in the literature was an additional aim consistent with scoping review methodology. Studies with or without a comparison group were eligible.

Context: Studies were eligible regardless of country, care setting, or healthcare system, provided they addressed combined anterior-posterior pelvic ring fixation in a predominantly adult trauma population.

Study Selection and Data Extraction

Two reviewers independently screened titles and abstracts followed by full-text review. Disagreements were resolved through discussion. Data were charted by one reviewer and verified by a second reviewer, with discrepancies resolved through discussion. Data extraction included study design, sample size, follow-up duration, patient characteristics (age, sex, fracture classification using Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association (AO/OTA) [25], Tile [26], Young-Burgess [27], and Denis [28] systems, mechanism of injury), fixation details (anterior and posterior fixation techniques, fixation sequence, imaging modality), SI screw outcomes (number of screws placed, malposition rate, definition of malposition, and assessment method), clinical outcomes (functional scores, complications, revision surgery, reduction quality), and risk factors (fracture pattern, number of screws, imaging modality, surgeon experience).

Risk of Bias Assessment

A formal risk of bias assessment was not performed, as this scoping review was designed to map the available evidence and identify reporting gaps rather than evaluate intervention effectiveness.

Data Synthesis

Data synthesis was primarily descriptive and narrative, given anticipated heterogeneity in study design, malposition definitions, imaging modalities, and outcome reporting. A narrative synthesis was performed to summarize risk factors for malposition and to evaluate comparisons of anterior-first versus posterior-first fixation sequences. Where appropriate, results were stratified by imaging modality (fluoroscopy vs CT/navigation) and fracture classification.

Results

Study Selection

The searches of PubMed, Embase, and CENTRAL identified 365 records. After removal of 52 duplicates, 313 records were screened by title and abstract, of which 128 underwent full-text assessment. A total of 116 reports were excluded at full text for the following reasons: wrong fixation or intervention (n = 66; e.g., isolated anterior or posterior fixation, absence of an iliosacral/SI screw construct, or no extractable combined anterior-posterior subgroup), full text available only in a language other than English (n = 23), wrong publication type (n = 17), wrong outcome (n = 5), wrong population (n = 3), and wrong study design (n = 2). Twelve studies satisfied all eligibility criteria and were carried forward to qualitative synthesis (Figure *1*).

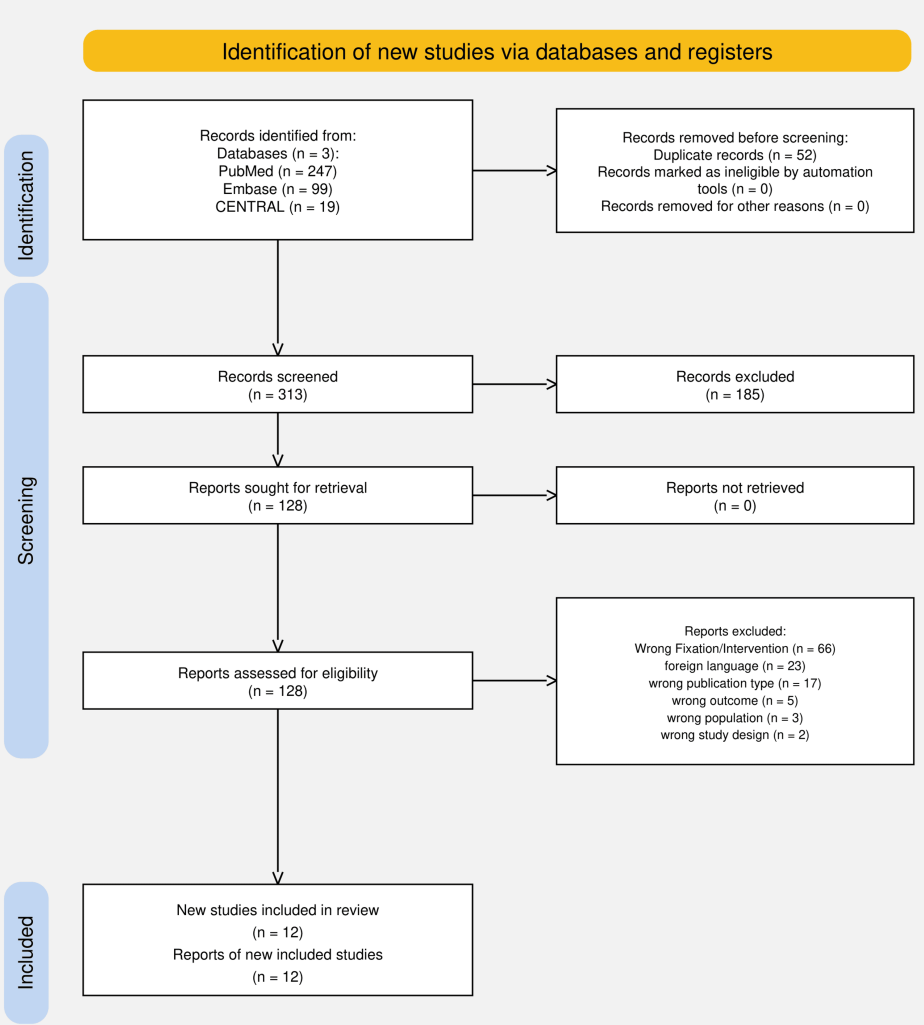


FIGURE 1: PRISMA-ScR flow diagram of study identification, screening, and inclusion.

PRISMA-ScR, Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews [21].

Characteristics of Included Studies

The 12 included studies were published between 2003 and 2023 and collectively reported on 716 patients. Outcomes were attributed to combined fixation only when they were reported specifically for the combined-fixation subgroup; outcomes available only for the whole study cohort were extracted, labeled as mixed-population data, and not attributed to combined fixation (for SI screw malposition, this applied to three studies, which are identified below). Of the 716 patients, 436 underwent combined anterior and posterior pelvic fixation within subgroups from which outcomes could be wholly or partially isolated; the combined-fixation subgroup was fully separable in seven studies and partially separable in five.

The records that were included in this study came from six countries, spanning four continents. The country with the largest study contribution was the United States (four studies: Ziran et al. [20], Mitchell et al. [8], Lindsay et al. [29], and Mardam-Bey et al. [12]), followed by East Asia (China: Chen et al. [11] and Liu et al. [9]; South Korea: Oh et al. [30] and Kim et al. [31]) and Egypt (Elzohairy and Salama [32] and Moussa et al. [4]), with single contributions from Switzerland (Abou-Khalil et al. [6]) and Germany (Wenning et al. [7]). The 12 included studies consisted of 10 retrospective cohort studies, one prospective case series, and one randomized controlled trial. Level of evidence was assigned using the Journal of Bone and Joint Surgery (JBJS) levels of evidence for primary research questions [33] and ranged from II to IV, with one study rated level II, five level III, and six level IV.

Patient populations across the included studies predominantly consisted of young to middle-aged adults who were injured through high-energy mechanisms; however, included patients' ages ranged from 12 to 91

years. Patients younger than 18 years were documented in one study, Ziran et al. [20] (mean age 42 years; range 12-78 years), which did not report how many of its patients were under 18; in addition, Moussa et al. [4] permitted enrollment from 16 years of age but did not report an age range. Because these patients could not be separated from the adult data, both studies were retained under the eligibility criteria described in the Methods. Ziran et al. reported no screw malpositions in any patient, and Moussa et al. did not assess screw position, so neither study affected the malposition numerators in this review. The mean or median age was clustered approximately around 28 and 48 years, and the proportion of high-energy mechanisms was 94-100% when data was provided. However, a notable exception was Wenning et al. [7], which analyzed an elderly fragility cohort (mean age 75.9 years, 16.7% male), in contrast to the other studies consisting of a majority of the cohort being male (45-82% male). The systems used for fracture classification were AO/OTA [25] in four studies, the Tile system [26] in one, multiple systems in six, and one study that did not report. Tile B and C predominance was displayed throughout the included studies.

Constructs of anterior fixation were heterogeneous, comprising pubic ramus or symphyseal plating [4,6,11,29-31], antegrade or retrograde superior pubic ramus screws [7,9,11], anterior external fixation (Mitchell et al. [8], with external fixation also used selectively in Lindsay et al. [29], Elzohairy and Salama [32], and Liu et al. [9]), and anterior subcutaneous internal fixation (Mardam-Bey et al. [12]).

Percutaneous iliosacral SI screw fixation was used in 11 out of the 12 studies for posterior fixation, with the exception of Mardam-Bey et al. [12], which compared transiliac-transsacral screws with unilateral iliosacral configurations. When reported, screw diameter ranged from 6.5 to 8.0 mm, with S1 placement in five studies, S1 and S2 in four studies, and three studies where the level was unspecified. The study characteristics are included in Table *1* below.

Study	Country	Design (LOE)	Patients, n total (combined-fix)	Fracture classification	Anterior fixation	Posterior fixation	Intra-op imaging	Follow-up (mo)
Ziran 2003 [20]	USA	Prospective case series (IV)	66 (16)	Multiple (YB/AO; mostly AO-C1)	Internal plating or external fixation (selected)	Iliosacral	CT-guided	25 (18-42)
Oh 2008 [30]	South Korea	Retrospective cohort (IV)	19 (19)	Multiple (Tile B2-C2 [26]; Denis [28])	Single 3.5 mm recon plate	Iliosacral	Fluoroscopy 2D	≥12
Chen 2012 [11]	China	Retrospective cohort (III)	58 (29)	Tile (C1-C3)	Pubic ramus screw or recon plate	Iliosacral vs percutaneous reconstruction plate	Fluoroscopy 2D	21.3 (12-36)
Kim 2013 [31]	South Korea	Retrospective cohort (IV)	29 (18)	AO/OTA (B, C)	Anterior (long recon) plating	Iliosacral	3D fluoroscopy	≥12
Mitchell 2015 [8]	USA	Retrospective cohort (IV)	129 (129)	NR	Anterior pelvic external fixation	Iliosacral	Fluoroscopy 2D	12 (2-97.6)
Lindsay 2016 [29]	USA	Retrospective cohort (III)	113 (51)	Bucholz 3 [34] / OTA 61-C1	Symphyseal plate / ext-fix / int-fix	Iliosacral	Fluoroscopy 2D	NR
Mardam-Bey 2016 [12]	USA	Retrospective cohort (III)	62 (44)	AO/OTA (61-B, -C1)	Plate / screws / InFix / ext-fix	TI-TS vs unilateral IS	Fluoroscopy 2D	41 (14-79)
Elzohairy 2017 [32]	Egypt	Retrospective cohort (IV)	70 (35)	Multiple (Tile B1-C2; Day [35]/Roy-Camille [36])	Plate-and-screw ORIF or supra-acetabular ext-fix	Iliosacral	Fluoroscopy 2D	48 (36-72)
Abou-Khalil 2020 [6]	Switzerland	Retrospective cohort (III)	36 (16)	AO/OTA (Tile B2/3, C)	3.5 mm R75 symphysis plate	Iliosacral	Mixed (fluoro + O-arm)	6 (4-12)
Wenning 2021 [7]	Germany	Retrospective cohort (III)	77 (48)	AO/OTA (54-C0, -C2)	Retrograde transpubic ramus screws	Iliosacral	Fluoroscopy 2D	≥6
Liu 2022 [9]	China	Retrospective cohort (IV)	17 (17)	Multiple (Tile B2-C2; Denis)	Plate / ramus screw / ext-fix	Iliosacral	Fluoroscopy 2D with patient-specific 3D-printed template	(12-25)
Moussa 2023 [4]	Egypt	RCT (II)	40 (14)	Multiple (Tile B2, C1; YB)	Pubic rami plating (Pfannenstiel)	Iliosacral	Fluoroscopy 2D	18 (12-24)

TABLE 1: Characteristics of the 12 included studies.

LOE, level of evidence; combined-fix, combined anterior–posterior fixation; NR, not reported; USA, United States of America; RCT, randomized controlled trial; YB, Young-Burgess [27]; AO, Arbeitsgemeinschaft für Osteosynthesefragen; OTA, Orthopaedic Trauma Association; AO/OTA: Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association [25], ORIF, open reduction and internal fixation; ext-fix, external fixation; int-fix, internal fixation; InFix, anterior subcutaneous internal fixator; recon, reconstruction; TI-TS, transiliac–transsacral; IS, iliosacral; CT, computed tomography; 2D, two-dimensional; 3D, three-dimensional; mm, millimeters; mo, months; Intra-op, intraoperative; n, number; vs, versus.

AOSI Screw Malposition Incidence

Eight of the 12 included studies reported SI screw malposition with an extractable numerator and denominator; in five of these (Liu et al. [9], Oh et al. [30], Chen et al. [11], Elzohairy and Salama [32], and Wenning et al. [7]), the numerator and denominator referred exclusively to patients treated with combined anterior-posterior fixation, whereas the remaining three reported malposition for a mixed cohort that included patients without combined fixation: Ziran et al. [20] (66 patients, of whom 16 had anterior fixation before iliosacral screw placement), Kim et al. [31] (29 patients, of whom 18 had combined fixation), and Abou-Khalil et al. [6] (22 percutaneously treated patients, of whom 16 had simultaneous anterior fixation) [6,7,9,11,20,30-32]. The other four studies did not analyze screw malposition due to study design on reduction quality (Lindsay et al. [29]), external-fixator complications (Mitchell et al. [8]), functional comparison (Mardam-Bey et al. [12]), or no report of systematic screw-position assessment (Moussa et al.

[4]).

Among the eight included studies, patient-level incidence ranged from 0-10.4%. Three studies recorded no malpositions (Liu et al. [9], 0/17; Ziran et al. [20], 0/66; Kim et al. [31], 0/29), while the other five recorded malposition rates of 2.9% (Elzohairy and Salama [32], 1/35), 4.5% (Abou-Khalil et al. [6], 1/22), 5.3% (Oh et al. [30], 1/19), 6.9% (Chen et al. [11], 2/29), and 10.4% (Wenning et al. [7], 5/48).

The definitions of malposition displayed considerable heterogeneity. There were no two studies that defined malposition identically. One study used the modified Gras system [37] (Liu et al. [9]). Two studies applied custom radiographic criteria: a millimeter-based cortical-perforation grade (Kim et al. [31]) and a binary adequate/inadequate judgement based on canal or foraminal intrusion (Oh et al. [30]). The remaining five studies did not use a formal grading system. Ziran et al. [20] assessed extraforaminal position within sacral bone on routine postoperative CT, and Wenning et al. [7] recorded malpositions identified on routine postoperative CT that required hardware change. The other three studies (Elzohairy and Salama [32], Abou-Khalil et al. [6], and Chen et al. [11]) used complication- and symptom-based definitions, recognizing malposition only when it resulted in neurological symptoms or required revision. Because asymptomatic cortical breaches and foraminal or canal intrusions are not captured by such definitions, symptom-based criteria may substantially underestimate radiographic screw malposition compared with systematic postoperative CT assessment. Rates from these studies therefore reflect clinically apparent malposition rather than true radiographic screw accuracy. When the study reported specific location, malpositions were foraminal (Abou-Khalil et al. [6] and Chen et al. [11], both associated with neuropathic pain) or within the sacral canal (Oh et al. [30], associated with neurological compromise); no anterior cortical or vascular malpositions were reported. The study-level malposition data are shown in Table *2*.

Study	Intra-op imaging	Post-op assessment	Malposition definition / classification	Patients with malposition, n/N (%)	Screws, n/N	Reported location
Ziran 2003 [20]	CT-guided	Post-op CT	No formal system; extraforaminal / within sacral bone	0/66 (0%)	0/NR	None
Kim 2013 [31]	3D fluoroscopy	Post-op CT	Custom: grade 2 (2–4 mm) / grade 3 (>4 mm) perforation = malposition	0/29 (0%)	0/31	None
Liu 2022 [9]	Fluoroscopy 2D with patient-specific 3D-printed template	Post-op CT	Modified Gras (grade 3 = cortical breach)	0/17 (0%)	0/20	None
Elzohairy 2017 [32]	Fluoroscopy 2D	NR (complication-defined)	No formal definition; complication-defined	1/35 (2.9%)	NR	Not specified (L5 root palsy)
Abou-Khalil 2020 [6]	Mixed (fluoro + O-arm)	Radiographs / clinical	No formal definition; neuropathic pain from malpositioned screw	1/22 (4.5%)	NR	Foraminal (S1/S3)
Oh 2008 [30]	Fluoroscopy 2D	Fluoroscopy	Binary: intrusion into sacral canal or foramen = inadequate	1/19 (5.3%)	1/NR	Sacral canal
Chen 2012 [11]	Fluoroscopy 2D	Fluoroscopy	No formal system; screw in sacral foramen causing nerve injury	2/29 (6.9%)	2/NR	Foraminal
Wenning 2021 [7]	Fluoroscopy 2D	Post-op CT	No formal system; identified on routine CT, requiring hardware change	5/48 (10.4%)	5/NR	Not specified
Moussa 2023 [4]	Fluoroscopy 2D	Radiographs	Not assessed	NR	NR	-
Lindsay 2016 [29]	Fluoroscopy 2D	Radiographs	Not assessed (reduction-quality study)	NR	NR	-
Mitchell 2015 [8]	Fluoroscopy 2D	Radiographs	Not assessed (ext-fixator complication study)	NR	NR	-
Mardam-Bey 2016 [12]	Fluoroscopy 2D	NR	Not assessed (functional-comparison study)	NR	NR	-

TABLE 2: Study-level SI screw malposition definitions, rates, and reported locations.

SI, sacroiliac; CT, computed tomography; NR, not reported; 2D, two-dimensional; 3D, three-dimensional; fluoro, fluoroscopy; mm, millimeters; L5, fifth lumbar nerve root; S1, first sacral level; S3, third sacral level; Intra-op, intraoperative; Post-op, postoperative; n, number; N, total number assessed.

Using crude aggregation across all eight studies, 10 of 265 patients (3.8%) had at least one malpositioned screw. This denominator is not restricted to the review's target population, because it includes the mixed cohorts of Ziran et al. [20], Kim et al. [31], and Abou-Khalil et al. [6]. Restricted to the five studies with combined-fixation-only denominators, nine of 148 patients (6.1%) had a malpositioned screw. Because Ziran et al. [20] and Kim et al. [31] reported no malpositions in any patient, their combined-fixation subgroups (16 and 18 patients, respectively) can also be counted, giving nine of 182 (4.9%) among patients confirmed to have undergone combined anterior-posterior fixation. In Abou-Khalil et al. [6], 16 of the 22 percutaneously treated patients had combined fixation, but the study did not report whether its single malposition occurred in this subgroup; including these patients would give nine or 10 of 198 (4.5%-5.1%). These aggregates are used only to display the general magnitude and cannot be formally pooled due to heterogeneity in the definitions of malposition, assessment methods, and denominators across studies; the study-level rates (0%-10.4%; Table *2*) are therefore the primary result. Reported separately by definition type, the five studies using imaging-based radiographic criteria (Ziran et al. [20], Kim et al. [31], Liu et al. [9], Oh et al. [30], and Wenning et al. [7]) identified malposition in six of 179 patients (3.4%; range 0%-10.4%). The three studies using clinical or symptom-based definitions (Elzohairy and Salama [32], Abou-Khalil et al.

[6], and Chen et al. [11]) identified malposition in four of 86 patients (4.7%; range 2.9%-6.9%). Because symptom-based definitions do not capture asymptomatic malposition, these two figures measure different outcomes and should not be compared directly. At the screw level, two studies reported a clean screw denominator: Liu et al. [9] and Kim et al. [31] reported zero of 51 malpositioned screws (0%), and Ziran et al. [20] reported no malpositioned screws but did not provide a total screw count. None of the studies specified whether individual patients had more than one malpositioned screw.

When malposition was stratified by modes of intraoperative imaging, a continuous pattern was observed. Two studies reported zero malpositions across a combined 95 patients when using 3D imaging with CT-guided placement (Ziran et al. [20]) and intraoperative 3D fluoroscopy (Kim et al. [31]). Conversely, the five studies relying on two-dimensional fluoroscopy reported nine of 148 patients were affected (6.1%), and the single study utilizing mixed fluoroscopy plus O-arm imaging (Abou-Khalil et al. [6]) reported one out of 22 affected patients. Stratification by postoperative assessment method was observed to be less discriminatory. A total of four studies used routine postoperative CT. Three reported no screw malpositions among a combined 112 patients (Liu et al. [9], Ziran et al. [20], Kim et al. [31]), whereas one study identified five malpositions in 48 patients (Wenning et al. [7]). These observations suggest, rather than demonstrate, a possible association between reported malposition rates and differences in intraoperative guidance, more than differences in postoperative assessment sensitivity. Given the small number of observational studies and their differences in patient selection, fixation constructs, and malposition definitions, this possible association requires confirmation in comparative studies.

Risk Factors for Malposition

Only one study formally analyzed candidate factors against SI screw malposition itself; a second study analyzed potential predictors of clinical outcome rather than screw position. Kim et al. [31] evaluated fracture type and treatment modality (combined anterior-posterior fixation versus posterior fixation alone) as potential predictors of malposition (defined as cortical perforation) and found that neither factor was significantly associated with malposition. Oh et al. [30] examined fracture type (Tile B and C) and reduction quality as predictors of clinical outcomes. Reduction quality was significantly associated with functional outcomes ($p = 0.001$), with 16 patients who achieved nearly anatomical reductions or better having satisfactory functional results according to the Rommens and Hessmann criteria [38]. In contrast, fracture type was not associated with functional outcomes ($p = 0.530$). Therefore, while achieving anatomic reduction appears to be associated with improved postoperative function, risk factors for SI screw malposition have been inadequately studied: only one small study tested candidate factors against screw position, without multivariate analysis. The absence of significant associations in the current literature reflects this lack of investigation and should not be interpreted as evidence that no such risk factors exist.

Anatomical and technical factors hypothesized to influence screw malposition were largely understudied. Only one study qualitatively evaluated sacral morphology (Ziran et al. [20]) and no study quantified a sacral dysmorphism rate in patients with malpositioned screws. Furthermore, none of the inclusion studies examined body mass index, S1 pedicle or sacral inclination angle, screw number, or surgeon experience as predictors of malposition. Though surgeon experience was described in several studies, it was not statistically tested [6,7,29-31]. The available risk-factor and fixation-sequence data are displayed in Table *3*.

Study	RF analysis performed	Factor(s) tested against screw position	Significant RF for malposition	Sequence reported	Sequence type	Outcomes compared by sequence
Kim 2013 [31]	Yes	Fracture type; treatment modality (combined vs posterior-alone)	None (no correlation)	Yes	Anterior-first	No (compared combined vs posterior-only fixation, not sequence)
Oh 2008 [30]	Yes	Reduction quality and fracture type vs clinical outcome (not malposition per se)	None for malposition	Yes	Anterior-first	No
Ziran 2003 [20]	No	-	-	Yes	Anterior-first	No
Liu 2022 [9]	No	-	-	Yes	Anterior-first	No
Chen 2012 [11]	No	-	-	Yes	Posterior-first	No
Lindsay 2016 [29]	No	Presence of anterior fixation vs reduction quality (not SI accuracy)	-	Yes	Mixed (injury-dependent)	No (compared presence vs absence of anterior fixation; reduction only)
Abou-Khalil 2020 [6]	No	-	-	No	NR	No
Moussa 2023 [4]	No	-	-	No	NR	No
Mitchell 2015 [8]	No	-	-	No	NR	No
Elzohairy 2017 [32]	No	-	-	No	NR	No
Mardam-Bey 2016 [12]	No	-	-	No	NR	No
Wenning 2021 [7]	No	-	-	No	NR	No

TABLE 3: Risk-factor analyses and fixation-sequence reporting by study.

RF, risk factor; SI, sacroiliac; NR, not reported; vs, versus.

Fixation Sequence

Of the 12 included studies, six explicitly documented the sequence of anterior and posterior fixation [9,11,20,29-31], while the other six did not report fixation sequence. Among the studies reporting sequence, four described initial anterior reduction and stabilization followed by SI screw placement (Ziran et al. [20], Kim et al. [31], Oh et al. [30], and Liu et al. [9]). In two of these studies, this approach facilitated indirect reduction of the posterior ring prior to SI screw insertion (Oh et al. [30], Kim et al. [31]). One study evaluated a posterior-first sequence, with posterior ring fixation performed in the prone position followed by supine anterior fixation (Chen et al. [11]). Lastly, one study used a mixed, injury-dependent sequence in which symphyseal disruptions were plated before posterior fixation, whereas other anterior injuries were addressed following posterior reduction (Lindsay et al. [29]).

Of the 12 studies, only two were analyzed for outcomes in relation to anterior fixation or fixation sequence. In Lindsay et al. [29], a subgroup of 62 patients without anterior stabilization was used as comparator. The presence of anterior fixation did not significantly affect posterior reduction quality but SI screw data was not reported. Kim et al. [31] revealed that isolated posterior fixation with SI screws alone did not correlate with screw malposition when compared with concomitant anterior plating with SI screws. Most importantly, and directly addressing this review's primary sequencing question, no included study reported SI screw

placement accuracy or malposition stratified by anterior-first versus posterior-first sequence; although six studies documented their fixation sequence, none compared screw accuracy between sequences, so the effect of fixation sequence on SI screw malposition cannot be determined from the current literature. The lack of direct comparison between screw accuracy by fixation sequence is the key finding of this review, and it highlights the particular gap in the current literature.

Clinical Outcomes

The Majeed score [39] was the most reported functional outcome. The results of the five included studies were typically favourable: median 87 with 71% good-to-excellent results (Abou-Khalil et al. [6]), a mean of 81.1 with 88.2% excellent or good (Chen et al. [11]), 88.2% excellent (Liu et al. [9]), a Group A mean of 77.5 with 70% excellent (Moussa et al. [4]), and comparable means of 71.7 and 71.9 across the two arms of Mardam-Bey et al. [12] ($p = 0.97$). Other functional scoring systems yielded similarly favorable results, including 85.7% of patients receiving good or excellent on a Pohlemann-based score [40] (Elzohairy and Salama [32]) and 84% achieving a satisfactory outcome rate using the Rommens and Hessmann criteria [38] (Oh et al. [30]).

Reduction quality was primarily graded as anatomical or satisfactory: 100% excellent (Liu et al. [9]), 86.5% excellent for symphyseal reduction (Mitchell et al. [8]), 85% anatomical intraoperatively (Moussa et al. [4]), and 84% satisfactory by the Matta criteria [41] (Oh et al. [30]). However, reporting was heterogeneous, and most studies did not distinguish anterior from posterior reduction quality. Lindsay et al. [29] documented excellent reductions in 89% of percutaneously treated patients, with combined excellent-and-good rates of 100%, and specifically found that anterior fixation did not significantly influence posterior reduction quality. Abou-Khalil et al. [6] applied a stricter Pohlemann radiological score [40], classifying only 27.2% of reductions as anatomical, illustrating how grading system and threshold materially affect reported reduction quality.

Overall postoperative complication rates were low. There were zero to two neurovascular complications per study and were mostly due to the direct consequence of a foraminal or canal screw malposition. In the studies that reported their outcomes [6,11,30], the neurovascular complications resolved after screw revision. Infection rates ranged from 0-15.5%, with the highest occurring in the anterior external-fixation cohort (Mitchell et al. [8], 15.5%) and in a combined anterior and posterior ring fixation cohort (Moussa et al. [4], 10%).

Lastly, there were multiple comparative studies concluding minimally invasive or percutaneous combined fixation was associated with lower blood loss and shorter operative time than open reduction and internal fixation of the posterior pelvic ring. There were no significant differences in functional scores, infection, or neurological injury (Abou-Khalil et al. [6], blood loss $p = 0.03$; Elzohairy and Salama [32], blood loss $p = 0.002$; Wenning et al. [7], shorter operative time and length of stay). Moussa et al. [4] instead compared combined fixation with posterior-only fixation and reported lower operative time and blood loss with posterior-only fixation. These comparisons were focused on perioperative and functional endpoints instead of SI screw accuracy, which was not compared between approaches in any study.

Discussion

Summary of Evidence

This review identified 12 eligible studies reporting on SI screw placement within combined anterior-posterior pelvic fixation, collectively describing 716 patients, of whom 436 underwent combined fixation in subgroups from which outcomes could be wholly or partially isolated. Eight of the 12 studies reported SI screw malposition with an extractable numerator and denominator; aggregated descriptively, 10 of 265 patients (3.8%) had at least one malpositioned screw (nine of 182 [4.9%] among patients confirmed to have combined fixation), with study-level rates ranging from 0% to 10.4% (Table *2*). This crude figure is presented for orientation only, as formal pooling was not undertaken given the marked heterogeneity in malposition definitions, assessment methods, and denominators across studies. With respect to the second objective of this review, no patient-, fracture-, or technical-level factor has yet been shown to be significantly associated with malposition, but this question has been minimally studied: only one study tested candidate variables (fracture type and treatment modality) against screw position, finding no significant association [31], while a second study tested fracture type and reduction quality against clinical outcome rather than screw position [30]. With respect to the third objective, whether fixation sequence influences screw accuracy, reduction quality, or clinical outcomes, sequence was explicitly reported in six of the 12 studies (50%) but was never analyzed against SI screw accuracy in any of them.

Malposition Incidence in the Context of Published Literature

The incidence range observed here (0-10.4%) is wider than, but not categorically inconsistent with, the 2.6% pooled rate reported for conventional fluoroscopy by Zwingmann et al. [18], although five of the eight reporting studies relied on 2D fluoroscopy alone. More recent reports have described fluoroscopic

malposition rates as high as 26% [19], and the 6.1% rate observed among the fluoroscopy-only studies in this review falls within this wider, more recently described range. This observation implies the 2013 pooled benchmark may understate the variability now reported in the literature, rather than conclude malposition risk has increased over time. The two studies using 3D intraoperative guidance, CT-guided placement (Ziran et al. [20]) and intraoperative 3D fluoroscopy (Kim et al. [31]), reported zero malpositions across a combined 95 patients, a pattern directionally consistent with the lower rates described for image-based and CT navigation in the same meta-analysis (1.3% and 0.1%, respectively). This consistency should be regarded as supportive rather than confirmatory. It rests on only two studies and 95 patients, and these studies may differ from the fluoroscopy-based studies in patient selection, fixation constructs, malposition definitions, and postoperative assessment, which limits direct comparison between imaging modalities. Both 3D guidance studies also reported malposition only for mixed cohorts that included patients without combined fixation, whereas the five fluoroscopy-only studies reported combined-fixation-only denominators, and stratification by postoperative assessment method in this review showed that detected malposition rates may have been associated more with intraoperative technique and case mix than with the sensitivity of postoperative imaging [7,9,20,31].

With respect to anatomic risk factors, this review is largely unable to engage with the background literature describing sacral dysmorphism prevalence [14-16]. Sacral morphology was assessed qualitatively in only one included study, and no study quantified a dysmorphism rate [20]. Whether the substantial anatomic risk attributed to dysmorphic sacral morphology in the broader literature is reflected among patients specifically undergoing combined anterior-posterior fixation therefore remains unanswered, an absence of data rather than a contradiction of existing evidence. Table *4* summarizes these comparisons against the published reference points alongside an explicit concordance assessment for each.

Outcome	This review	Reference literature	Concordance assessment
Malposition rate - conventional fluoroscopy	6.1% (9/148; 5 studies [7,9,11,30,32])	2.6% [18]; up to 26% in more recent series [19]	Falls within the wider range now reported in the literature; higher than the 2013 benchmark but not discordant with more recent estimates, plausibly reflecting heterogeneous malposition definitions, assessment methods, and case mix (one elderly fragility-fracture cohort [7] contributed 5 of the 9 malpositions)
Malposition rate - intraoperative 3D fluoroscopy	0% (0/29; 1 study, Kim 2013 [31])	1.3% for 2D/3D image-based navigation [18]	Concordant in direction (lower than fluoroscopy); based on a single study and cannot be generalized
Malposition rate - CT navigation	0% (0/66; 1 study, Ziran 2003 [20])	0.1% [18]	Concordant in direction; based on a single study and cannot be generalized
Sacral dysmorphism prevalence	Not quantified in any study; assessed qualitatively in 1/12 [20]	15-53% in trauma populations [14-16]	Cannot be compared - absence of data in this review, not a contradictory finding
Fracture pattern as a risk factor	Tested against screw position in 1/12 studies [31], with no significant association; tested against clinical outcome only in 1 further study [30]	Biomechanically plausible (Tile B vs C [26]) but not consistently confirmed empirically elsewhere	Inconclusive in both this review and the broader literature
Fixation sequence vs screw accuracy	Not analyzed in any of the 12 included studies [4,6-9,11,12,20,29-32]	Identified as an unresolved question in prior literature (see Introduction)	Concordant gap - confirms, rather than newly identifies, a pre-existing evidence void

TABLE 4: Comparison of this review's findings with published reference points.

RF, risk factor; 2D, two-dimensional; 3D, three-dimensional; CT, computed tomography; vs, versus. Concordance assessments reflect direction of effect only where sample sizes in this review are too small to support quantitative comparison.

Imaging Modality

When malposition was stratified by intraoperative imaging, a descriptive pattern was observed, but the estimates were imprecise and their confidence intervals overlapped (zero of 95 with 3D guidance, exact 95% CI 0%-3.8% [42]; nine of 148 with two-dimensional fluoroscopy, 95% CI 2.8%-11.2%), so the data do not establish a difference between modalities. In addition, Wenning et al. [7], an elderly fragility-fracture cohort, contributed five of the nine fluoroscopic malpositions; without this study, the fluoroscopy stratum was four of 100 (4.0%). The two studies using advanced intraoperative 3D guidance reported no malpositions, whereas the five studies relying on two-dimensional fluoroscopy reported nine of 148 affected patients (6.1%). The single mixed-modality study (fluoroscopy plus O-arm) reported one of 22 [6]. The increased malposition rate observed using the O-arm in this study was largely attributed to inexperience with the O-arm and excessive intraoperative workflow requirements for positioning and imaging [6]. This pattern is consistent with the technical limitation described by Zuelzer et al. [17], who noted that non-collinear S1 and S2 angles can make it difficult to obtain a single fluoroscopic view tangential to both segments, plausibly increasing the risk of misplacement under two-dimensional guidance alone; none of the included studies, however, reported S1-S2 angle data, so this review can describe the association only as plausible rather than demonstrated [17]. These findings are consistent with a modality-related gradient but do not on their own support a categorical claim that any single modality is optimal for combined anterior-posterior constructs specifically.

Anatomy and Fracture Pattern

Fracture pattern was tested against screw position in only one study, which found no correlation between fracture type and cortical perforation; treatment modality (combined versus posterior-only fixation) was likewise not correlated with perforation in the same study [31]. Oh et al. [30] examined fracture type and reduction quality in relation to clinical outcome rather than malposition itself, finding that reduction quality predicted clinical outcome ($p = 0.001$) while fracture type did not ($p = 0.530$). No included study analyzed body mass index, screw number, S1 pedicle angle, or sacral inclination angle as predictors of malposition, despite these factors being discussed in the broader anatomic and biomechanical literature. As a result, this review can therefore neither confirm nor refute their relevance to combined anterior-posterior constructs specifically. The planned analysis, defined before screening, specified stratification of results by fracture classification where appropriate; in practice, this was not meaningfully achievable beyond the single study noted above, since most included studies either pooled multiple Tile or AO/OTA subtypes without subtype-specific malposition reporting or did not report fracture classification against outcome at all, a data limitation rather than a deviation from the planned analysis.

Fixation Sequence

Six of the 12 studies reported fixation sequence: four described an anterior-first approach, one described a posterior-first approach with intraoperative repositioning, and one used a mixed, injury-dependent sequence [9,11,20,29-31]. Of these, only two studies analyzed any outcome in relation to sequence or the presence of anterior fixation. Lindsay et al. [29] found that the presence of anterior fixation did not significantly affect posterior reduction quality when comparing pre- and post-operative plain radiographs, while Kim et al. [31] found that treatment modality did not correlate with screw perforation. Neither study, nor any other included study, reported SI screw placement accuracy stratified by anterior-first versus posterior-first sequence. This absence of any direct sequence-to-accuracy comparison is identified here as a principal finding of this review in its own right, rather than as an incidental limitation, and therefore represents the clearest gap in the current evidence base.

Advances

Within the included literature, the clearest technical advance is the shift from fluoroscopy-only guidance toward CT-guided placement and intraoperative 3D fluoroscopy (see Imaging modality, above). A secondary advance is the move toward more granular, purpose-built malposition grading, the modified Gras classification [9] and a millimeter-based cortical-perforation grade [31], in place of the complication- or symptom-defined criteria used in most of the older included studies. Broader developments such as formal sacral dysmorphism scoring systems and S1 pedicle angle assessment are established elsewhere in the literature but were not demonstrated within the studies included in this review and should not be attributed to this evidence base.

Gaps

No included study was designed primarily to evaluate SI screw accuracy in the specific context of combined anterior-posterior fixation; the relevant data was extracted from subgroups of studies with broader aims. Fixation sequence was reported in only half of the included studies; of these, two examined an outcome in relation to the presence of anterior fixation rather than to sequence itself (Lindsay et al. [29]: posterior reduction quality; Kim et al. [31]: screw perforation), and no study analyzed any outcome against fixation sequence (anterior-first vs. posterior-first) specifically. Malposition definitions were heterogeneous across

all eight reporting studies, with no two studies using an identical definition and only one applying a named, published classification system (Table 2). Risk-factor analysis of screw position was confined to univariate testing in a single study [31] (a second study tested predictors of clinical outcome only [30]), with no multivariate modeling undertaken anywhere in the included literature. Finally, the evidence base remains predominantly lower-level: 10 of the 12 included studies were retrospective cohorts, with only one prospective case series and one randomized controlled trial [4,20]. Table 5 maps each of these gaps to the corresponding recommendation developed further under Research Recommendations, below.

Gap identified	Supporting evidence from this review	Corresponding recommendation
Fixation sequence never analyzed against screw accuracy	6/12 studies reported sequence; 0/12 analyzed it against malposition or any accuracy outcome	Prospective multicenter trial comparing anterior-first vs posterior-first sequencing, with CT-assessed accuracy as the primary outcome
Heterogeneous, non-standardized malposition definitions	4 distinct definitional approaches across 8 reporting studies; only 1 used a named, published classification	Adopt a standardized malposition classification (e.g., a modified Gras-type grading) across future studies
Minimal risk-factor analysis	Only 1/12 studies tested any candidate variable against screw position (1 further study against clinical outcome); no multivariate modeling in any included study	Multivariate analysis controlling for fracture pattern, BMI, sacral morphology, imaging modality, and surgeon experience
Sacral dysmorphism unassessed	Quantified in 0/12 studies; assessed only qualitatively in 1/12	Routine preoperative CT-based sacral morphology classification, reported as a standard methods item
Predominantly low-level evidence	10/12 studies retrospective cohorts; 1 prospective case series; 1 RCT	Prioritize prospective and randomized designs in future SI screw accuracy research
Advanced-imaging strata underpowered	Only 1 study each for intraoperative 3D fluoroscopy and CT guidance	Larger multicenter cohorts stratified explicitly by intraoperative imaging modality

TABLE 5: Summary of evidence gaps and corresponding research recommendations.

BMI, body mass index; RCT, randomized controlled trial; SI, sacroiliac; CT, computed tomography; vs, versus.

Evidence of Practice

Despite these gaps, several observations support cautious clinical application of combined anterior-posterior fixation for treatment of pelvic ring fractures. The absence of detected malposition in both studies using 3D intraoperative guidance supports continued consideration of CT-guided or 3D fluoroscopy-guided techniques, although neither study provided a direct comparative estimate of complication rates, and this review therefore cannot establish that 3D guidance lowers complication rates. The consistent finding across comparative studies that minimally invasive combined fixation reduces blood loss and operative time relative to open approaches, without a demonstrated cost in functional outcome, infection, or neurological injury, supports the continued use of percutaneous techniques when anatomically feasible [4,6,7,32]. In instances where percutaneous fixation was not applicable due to inability to achieve an acceptable closed reduction or anatomic constraints (sacral dysmorphism, crescent fractures, or sacral area III fractures) where the target corridor lacks sufficient effective length for safe fixation, an open approach was necessary [6,11,20,32]. Surgeon experience, while not statistically tested in any included study, was consistently reported as a feature of the surgical teams across the included studies [6,7,29-31], consistent with the technically demanding nature of the procedure [13]. Notably, Wenning et al.'s study [7], which reported the highest observed malposition rate in this review, was also performed by an experienced surgical team, underscoring that surgeon experience alone does not appear to eliminate malposition risk.

Moussa et al. [4] was the only randomized trial to compare combined fixation against posterior fixation alone (Kim et al. [31] also compared these approaches, but only for screw perforation), finding significantly less blood loss and shorter operative time with posterior-only fixation, but no statistically significant difference in functional or radiologic outcomes between the two arms. This finding is consistent with the biomechanical rationale that rigid posterior fixation alone may provide approximately 70-85% of the torsional and axial load resistance required for certain vertical shear injuries. However, this review is not positioned to resolve the broader question of when posterior fixation alone is biomechanically sufficient.

Clinical and Research Implications

This review has several strengths that support confidence in its findings, including a systematic, multi-database search strategy conducted in accordance with PRISMA-ScR reporting guidelines [21] and JBI scoping review methodology [24], and dual independent screening; to our knowledge, based on a review of the existing literature and on the prior systematic reviews and meta-analyses identified by our database search and examined during screening (including Zwingmann et al. [18], none of which restricted analysis to combined anterior-posterior constructs or examined fixation sequence), it is also the first review to focus specifically on SI screw accuracy within the combined anterior-posterior fixation population and the first to systematically examine fixation sequence as a variable potentially influencing screw placement accuracy. Building on these strengths, the findings of this review support three specific changes proportionate to the strength of the evidence reviewed. First, future studies of combined anterior-posterior pelvic fixation should report fixation sequence as a standard methodological item, regardless of whether sequence is a primary research question. Second, a standardized, published malposition classification should be adopted across future studies; the near-total absence of definitional overlap among the eight reporting studies in this review materially limits comparability and precludes formal pooling. Third, given that current evidence cannot determine whether imaging modality, anatomic risk factors, or fixation sequence independently influence SI screw accuracy in combined constructs, intraoperative imaging decisions should continue to be guided by surgeon judgment, available resources, and individual anatomy rather than by a single preferred protocol derived from this review.

Research Recommendations

Three research priorities follow from the gaps identified above. First, a prospective, multicenter study directly comparing anterior-first versus posterior-first fixation sequence, with CT-assessed SI screw accuracy as the primary outcome, is the single highest-priority study design indicated by this review. Second, future studies of pelvic fixation should adopt and consistently apply a standardized, published malposition classification (e.g., a modified Gras-type system). Third, future studies of combined anterior-posterior fixation should report a minimum dataset comprising, at minimum, fixation sequence, intraoperative imaging modality, postoperative assessment method, sacral morphology/dysmorphism status, and per-screw (in addition to per-patient) malposition outcomes.

Limitations

This review is limited by substantial heterogeneity in study design, fixation technique, intraoperative imaging modality, and definitions of screw malposition across the 12 included studies. Malposition was assessed using heterogeneous criteria ranging from formal radiographic grading systems to complication- or symptom-based definitions. This definitional and denominator heterogeneity limited direct comparison across studies and precluded formal meta-analytic pooling for the headline incidence figure. Therefore, a crude descriptive estimate was used rather than a pooled incidence. Reporting of fixation sequence was also incomplete, with only six of 12 studies explicitly documenting the sequence of anterior and posterior fixation. Of these studies, only two examined any outcome relative to anterior fixation or sequence, and no studies directly reported SI screw malposition rates in anterior-first versus posterior-first sequencing. Thus, there is insufficient evidence to determine whether fixation sequence influences screw accuracy.

Additionally, this study utilized a predominantly retrospective evidence base, with 10 of 12 studies using retrospective cohort designs, introducing potential for selection bias and confounding. In addition, only one study formally analyzed candidate factors against screw malposition (a second analyzed clinical outcome only), so the absence of identified predictors reflects limited investigation rather than evidence of no association. Important potential technical and anatomic factors including sacral morphology, screw number, S1 pedicle angle, sacral inclination angle, and surgeon experience were either inconsistently reported or not formally evaluated. No formal risk-of-bias assessment was performed, consistent with the scoping review methodology, which limits the ability to systematically assess the methodological quality and internal validity of the included studies. Finally, this review was restricted to English-language, full-text publications, which may have excluded relevant studies published in other languages or published abstracts not yet available in full text. In addition, only three databases were searched, without grey literature, trial registries, or backward and forward citation searching; because fixation sequence is typically reported only within the operative technique section of full texts and is rarely indexed in titles or abstracts, some studies that reported sequence may not have been retrieved. The relatively small number of eligible studies, combined with the inconsistent reporting of malposition definitions, fixation sequence, and other technical variables, further limits the generalizability and strength of the available evidence.

Conclusions

The available evidence suggests that SI screw malposition is an important but infrequent complication of posterior pelvic fixation. No factor has yet been shown to be significantly associated with malposition in the limited available evidence, and the available literature is insufficient to determine whether fracture pattern, sacral morphology, or other anatomic and technical characteristics independently predict screw accuracy. Advanced 3D intraoperative guidance warrants further prospective study as a potential factor influencing screw accuracy. The effect of fixation sequence on screw accuracy remains unknown. Future prospective, multicenter studies should directly compare fixation sequences using standardized malposition

definitions and CT-based assessment of screw accuracy, while routinely reporting key anatomic, technical, and imaging variables. Such studies would address the principal evidence gap identified by this review and provide a stronger basis for optimizing the safety and technique of combined anterior-posterior pelvic fixation.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

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References

1. Nork SE, Jones CB, Harding SP, Mirza SK, Routt ML Jr: Percutaneous stabilization of U-shaped sacral fractures using iliosacral screws: technique and early results. J Orthop Trauma. 2001, 15:238-46. 10.1097/00005131-200105000-00002
2. Ruatti S, Boudissa M, Kerschbaumer G, Milaire M, Tonetti J: Effectiveness of closed reduction and percutaneous fixation of isolated sacral fractures. Functional outcomes and sagittal alignment after 3.6 years in 20 patients. Orthop Traumatol Surg Res. 2019, 105:719-25. 10.1016/j.otsr.2019.02.021
3. van den Bosch EW, van Zwienen CM, van Vugt AB: Fluoroscopic positioning of sacroiliac screws in 88 patients. J Trauma. 2002, 53:44-8. 10.1097/00005373-200207000-00009
4. Moussa IS, Sallam AM, Mahmoud AK, Elzaher EH, Nagy AM, Eid AS: Combined anterior and posterior ring fixation versus posterior ring fixation alone in the management of unstable Tile B and C pelvic ring injuries: a randomized controlled trial. Chin J Traumatol. 2023, 26:48-59. 10.1016/j.cjtee.2022.06.003
5. Chen PH, Hsu WH, Li YY, Huang TW, Huang TJ, Peng KT: Outcome analysis of unstable posterior ring injury of the pelvis: comparison between percutaneous iliosacral screw fixation and conservative treatment. Biomed J. 2013, 36:289-94. 10.4103/2319-4170.112757
6. Abou-Khalil S, Steinmetz S, Mustaki L, Leger B, Thein E, Borens O: Results of open reduction internal fixation versus percutaneous iliosacral screw fixation for unstable pelvic ring injuries: retrospective study of 36 patients. Eur J Orthop Surg Traumatol. 2020, 30:877-84. 10.1007/s00590-020-02646-x
7. Wenning KE, Yilmaz E, Schildhauer TA, Hoffmann MF: Comparison of lumbopelvic fixation and iliosacral screw fixation for the treatment of bilateral sacral fractures. J Orthop Surg Res. 2021, 16:604. 10.1186/s13018-021-02768-w
8. Mitchell PM, Corrigan CM, Patel NA, et al.: 13-year experience in external fixation of the pelvis: complications, reduction and removal. Eur J Trauma Emerg Surg. 2016, 42:91-6. 10.1007/s00068-015-0499-7
9. Liu F, Yu J, Yang H, Cai L, Chen L, Lei Q, Lei P: Iliosacral screw fixation of pelvic ring disruption with tridimensional patient-specific template guidance. Orthop Traumatol Surg Res. 2022, 108:103210. 10.1016/j.otsr.2022.103210
10. Naisan M, Joumah M, Brenneis M, Richter M, Drees P, Hartung P: Unilateral sacral fragility fractures: a comparative study of unilateral vs. bilateral minimally invasive osteosynthesis. Eur Spine J. 2025, 34:5018-22. 10.1007/s00586-025-09081-8
11. Chen HW, Liu GD, Fei J, Yi XH, Pan J, Ou S, Zhou JH: Treatment of unstable posterior pelvic ring fracture with percutaneous reconstruction plate and percutaneous sacroiliac screws: a comparative study. J Orthop Sci. 2012, 17:580-7. 10.1007/s00776-012-0257-1
12. Mardam-Bey SW, Beebe MJ, Black JC, et al.: The effect of transiliac-transsacral screw fixation for pelvic ring injuries on the uninjured sacroiliac joint. J Orthop Trauma. 2016, 30:463-8. 10.1097/BOT.0000000000000622
13. Routt ML Jr, Simonian PT, Mills WJ: Iliosacral screw fixation: early complications of the percutaneous technique. J Orthop Trauma. 1997, 11:584-9. 10.1097/00005131-199711000-00007

14. Boudissa M, Carmagnac D, Kerschbaumer G, Ruatti S, Tonetti J: Screw misplacement in percutaneous posterior pelvic iliosacral screwing with and without navigation: a prospective clinical study of 174 screws in 127 patients. Orthop Traumatol Surg Res. 2022, 108:103213. 10.1016/j.otsr.2022.103213
15. Hasenboehler EA, Stahel PF, Williams A, Smith WR, Newman JT, Symonds DL, Morgan SJ: Prevalence of sacral dysmorphia in a prospective trauma population: implications for a "safe" surgical corridor for sacro-iliac screw placement. Patient Saf Surg. 2011, 5:8. 10.1186/1754-9493-5-8
16. Kaiser SP, Gardner MJ, Liu J, Routt ML Jr, Morshed S: Anatomic determinants of sacral dysmorphism and implications for safe iliosacral screw placement. J Bone Joint Surg Am. 2014, 96:e120. 10.2106/JBJS.M.00895
17. Zuelzer DA, Ryan L, Westbrooks T, Routt ML Jr: Iliosacral screws can be placed with precision by adjusting the pelvic inlet between S1 and S2. J Orthop Trauma. 2023, 37:607-13. 10.1097/BOT.0000000000002698
18. Zwingmann J, Hauschild O, Bode G, Südkamp NP, Schmal H: Malposition and revision rates of different imaging modalities for percutaneous iliosacral screw fixation following pelvic fractures: a systematic review and meta-analysis. Arch Orthop Trauma Surg. 2013, 133:1257-65. 10.1007/s00402-013-1788-4
19. Gilli A, Daoudi S, Moreau PE, Riouallon G: Accuracy of sacroiliac screw placement using O-arm and 3D navigation: a case series. Eur J Orthop Surg Traumatol. 2025, 35:308. 10.1007/s00590-025-04402-5
20. Ziran BH, Smith WR, Towers J, Morgan SJ: Iliosacral screw fixation of the posterior pelvic ring using local anaesthesia and computerised tomography. J Bone Joint Surg Br. 2003, 85:411-8. 10.1302/0301-620x.85b3.13119
21. Tricco AC, Lillie E, Zarin W, et al.: PRISMA Extension for Scoping Reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med. 2018, 169:467-73. 10.7326/M18-0850
22. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A: Rayyan—a web and mobile app for systematic reviews. Syst Rev. 2016, 5:210. 10.1186/s13643-016-0384-4
23. Peters MD, Godfrey CM, Khalil H, McInerney P, Parker D, Soares CB: Guidance for conducting systematic scoping reviews. Int J Evid Based Healthc. 2015, 13:141-6. 10.1097/XEB.0000000000000050
24. Peters MD, Marnie C, Tricco AC, et al.: Updated methodological guidance for the conduct of scoping reviews. JBI Evid Synth. 2020, 18:2119-26. 10.11124/JBIES-20-00167
25. Marsh JL, Slongo TF, Agel J, et al.: Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma. 2007, 21:S1-133. 10.1097/00005131-200711101-00001
26. Tile M: Pelvic ring fractures: should they be fixed? . J Bone Joint Surg Br. 1988, 70:1-12. 10.1302/0301-620X.70B1.3276697
27. Burgess AR, Eastridge BJ, Young JW, et al.: Pelvic ring disruptions: effective classification system and treatment protocols. J Trauma. 1990, 30:848-56. 10.1097/00005373-199007000-00015
28. Denis F, Davis S, Comfort T: Sacral fractures: an important problem. Retrospective analysis of 236 cases . Clin Orthop Relat Res. 1988, 227:67-81.
29. Lindsay A, Tornetta P 3rd, Diwan A, Templeman D: Is closed reduction and percutaneous fixation of unstable posterior ring injuries as accurate as open reduction and internal fixation?. J Orthop Trauma. 2016, 30:29-33. 10.1097/BOT.0000000000000418
30. Oh CW, Kim PT, Kim JW, et al.: Anterior plating and percutaneous iliosacral screwing in an unstable pelvic ring injury. J Orthop Sci. 2008, 13:107-15. 10.1007/s00776-007-1201-7
31. Kim JW, Oh CW, Oh JK, et al.: Percutaneous iliosacral screwing in pelvic ring injury using three-dimensional fluoroscopy. J Orthop Sci. 2013, 18:87-92. 10.1007/s00776-012-0320-y
32. Elzohairy MM, Salama AM: Open reduction internal fixation versus percutaneous iliosacral screw fixation for unstable posterior pelvic ring disruptions. Orthop Traumatol Surg Res. 2017, 103:223-7. 10.1016/j.otsr.2016.12.002
33. Wright JG, Swiontkowski MF, Heckman JD: Introducing levels of evidence to the journal . J Bone Joint Surg Am. 2003, 85:1-3. 10.2106/00004623-200301000-00001
34. Bucholz RW: The pathological anatomy of Malgaigne fracture-dislocations of the pelvis . J Bone Joint Surg Am. 1981, 63:400-4. 10.2106/00004623-198163030-00013
35. Day AC, Kinmont C, Bircher MD, Kumar S: Crescent fracture-dislocation of the sacroiliac joint: a functional classification. J Bone Joint Surg Br. 2007, 89:651-8. 10.1302/0301-620X.89B5.18129
36. Roy-Camille R, Saillant G, Gagna G, Mazel C: Transverse fracture of the upper sacrum. Suicidal jumper's fracture. Spine. 1985, 10:838-45. 10.1097/00007632-198511000-00011
37. Gras F, Marintschev I, Wilharm A, Klos K, Mückley T, Hofmann GO: 2D-fluoroscopic navigated percutaneous screw fixation of pelvic ring injuries - a case series. BMC Musculoskelet Disord. 2010, 11:153. 10.1186/1471-2474-11-153
38. Rommens PM, Hessmann MH: Staged reconstruction of pelvic ring disruption: differences in morbidity, mortality, radiologic results, and functional outcomes between B1, B2/B3, and C-type lesions. J Orthop Trauma. 2002, 16:92-8. 10.1097/00005131-200202000-00004
39. Majeed SA: Grading the outcome of pelvic fractures . J Bone Joint Surg Br. 1989, 71:304-6. 10.1302/0301-620X.71B2.2925751
40. Pohlemann T, Bosch U, Gänsslen A, Tscherne H: The Hannover experience in management of pelvic fractures. Clin Orthop Relat Res. 1994, 305:69-80. 10.1097/00003086-199408000-00010
41. Matta JM, Tornetta P 3rd: Internal fixation of unstable pelvic ring injuries . Clin Orthop Relat Res. 1996, 329:129-40. 10.1097/00003086-199608000-00016
42. Clopper CJ, Pearson ES: The use of confidence or fiducial limits illustrated in the case of the binomial . Biometrika. 1934, 26:404-13. 10.1093/biomet/26.4.404