

# Fluoroscopy-Guided Versus 3D Navigated Percutaneous Sacroiliac Screw Fixation: A Comparison of Radiation Exposure and Surgical Duration

Tyler J. Chavez, MD; Jeremiah M. Langsfeld, BS; Solomon Oloyede, MD; Gordon Lee, MD; Urvij Modhia, MD

The University of New Mexico Department of Orthopaedics & Rehabilitation, Albuquerque, New Mexico

**Corresponding Author** Tyler J. Chavez, MD. Department of Orthopaedics & Rehabilitation, The University of New Mexico. 1 University of New Mexico, MSC10 5600, Albuquerque, NM 87131 (email: tyjchavez@salud.unm.edu).

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## ABSTRACT

**Background:** Pelvic ring injuries are complex surgical challenges requiring significant radiation exposure for safe placement of sacroiliac (SI) screw fixation. Traditionally, SI fixation has been performed with conventional C-arm fluoroscopy to guide screw placement. 3D navigated imaging is a technique that uses fluoroscopic scans and a navigation tracker to guide screws in space. The purpose of this study is to characterize a single institution's experience with navigated SI fixation and the resulting radiation exposure to patient and staff.

**Methods:** Records of 60 patients who underwent SI fixation using either conventional fluoroscopy (43) or 3D navigation (17) were reviewed. Exposure data (radiation time, radiation dose, and surgical duration) were compared. The data were evaluated for correlations between the primary outcomes and patient factors (age and body mass index (BMI)).

**Results:** Radiation time per screw was significantly less in the 3D navigation group (19.5 seconds vs 39.2 seconds,  $P < 0.001$ ). However, there was no difference in radiation dose or surgical duration between the two groups. There was a positive correlation between radiation dose per screw and BMI. The primary outcomes were not affected by the exclusion of patients with a BMI greater than 40.

**Conclusion:** The results of this single-institution study demonstrate a significant decrease in radiation time when performing SI fixation using a 3D navigated technique compared to conventional fluoroscopy. However, this reduction did not translate to a decreased radiation dose or a shorter surgical duration. These findings suggest noninferiority of the navigated technique when compared to conventional fluoroscopy, with the added benefit of reduced radiation exposure to operating room staff when their physical positioning during imaging is considered.

**Keywords:** Acute Care Surgery; Radiation Exposure; Sacroiliac Joint; Surgical Navigation Systems

## INTRODUCTION

Pelvic ring disruptions are severe bony and ligamentous injuries, most commonly caused by blunt trauma such as motor vehicle accidents or falls from a height.<sup>1</sup> These injuries are generally severe and are associated with major hemorrhage, craniocerebral injury, abdominal injury, and death. They typically occur after high-energy mechanisms of injury in patients between 18 years of age and 35 years of age.<sup>2</sup> However, there is a bimodal age distribution, with a similar peak of prevalence in women over 70 years of age, often resulting from low-energy injury mechanisms in the setting of poor bone quality.

Sacroiliac (SI) disruptions, in particular, present complex surgical challenges that require safe screw

fixation to facilitate mobilization. When compared to non-operative management, surgical fixation of these injuries leads to earlier weight bearing and mobilization, shorter hospital stays, and improved functional outcomes.<sup>3,4</sup> The goals of operative intervention are to restore the biomechanical axis and stability of the pelvic ring, allowing the patient to progress with weight bearing, facilitate mobilization, and ultimately heal with normal anatomical alignment. Early surgical intervention is therefore critical in reducing the risks associated with immobility, such as pneumonia, thromboembolic events, pressure ulcers, and psychological complications.<sup>5</sup>

Historically, pelvic ring injuries were treated non-operatively or with large open approaches and fixation.

Fortunately, with advances in intraoperative imaging technologies, surgical stabilization is now typically performed using a percutaneous, minimally invasive approach. Compared to open treatment, percutaneous fixation requires less operative time, results in less bleeding, and is associated with lower morbidity.<sup>6</sup> Percutaneous SI screw fixation is typically performed using conventional C-arm intraoperative fluoroscopy to guide safe screw placement with osseous corridors visualized on x-ray. However, this technique requires obtaining multiple intraoperative fluoroscopic images, exposing both the patient and the healthcare team to harmful radiation.

Alternatively, computer-assisted navigation is a technique that uses an intraoperative 3D fluoroscopy scan along with a navigation tracker placed on a fixed bony landmark. This technique reduces the amount of intraoperative fluoroscopy required for implant positioning and fixation.<sup>7</sup> There has been previous research describing the differences between conventional fluoroscopy and 3D navigated techniques – the majority of which demonstrates benefits of 3D techniques in respect to screw placement, operative time, and radiation exposure.<sup>1,5,8-11</sup>

The purpose of this study is to add to the existing body of literature by characterizing this institution's experience with 3D navigated SI fixation and its impact on radiation exposure to both the patient and surgical staff. The authors hypothesize that SI screw fixation using 3D navigated imaging will result in less radiation exposure (measured as radiation time and dose) and a shorter surgical duration compared to similar cases using traditional fluoroscopic imaging techniques.

## METHODS

All surgical cases of SI screw fixation were retrospectively reviewed at The University of New Mexico from September 2022 to May 2024. Institutional Review Board approval was obtained (#23-087), and patient consent was waived due to the observational nature of the study.

All patients undergoing either conventional or navigated SI screw fixation for pelvic ring injuries during the study period were considered. The selection criteria were based on the type of surgical procedure, which included percutaneous posterior pelvic ring screw fixation. Both SI screw fixation and trans-sacral screw fixation were included. Exclusion criteria included incomplete patient records, missing surgical or imaging data, any anterior pelvic ring fixation, and patients undergoing other surgical procedures during the same anesthesia event, typically in the setting of polytrauma.

**The primary outcomes assessed were:**

**1. Radiation Time:** Defined as the total duration of radiation exposure during the procedure, measured in

minutes, as recorded by the fluoroscopy system used (Ziehm Vision RFD 3D, Orlando FL). This was then divided by the number of screws placed.

**2. Radiation Dose:** Measured as the total dose of radiation received by the patient, reported in milliGray (mGy), as recorded by the fluoroscopy system used during surgery (Ziehm Vision RFD 3D, Orlando FL). This similarly was then divided by the number of screws placed.

**3. Surgical Duration:** Defined as the time from the initial incision to the closure of the surgical wound, measured in minutes, as recorded in the operating room (OR) anesthesia record.

Patient demographic information, including age, sex, and body mass index (BMI), was extracted from the electronic medical record to control for potential confounders. Outcome data were also obtained directly from the procedural logs maintained by the surgical and radiology teams. All data were anonymized prior to analysis.

The primary comparison was between radiation time, radiation dose, and surgical duration for the two surgical techniques. Descriptive statistics were used to summarize the outcomes for each technique. A Mann-Whitney U test was used to compare means between groups, given the non-normally distributed data. Median values were primarily compared, rather than the mean values, to limit the effect of outliers. The data were then evaluated for correlations between the primary outcomes and patient factors, such as age and BMI. These correlations informed further sub-group analysis. Statistical significance was set at a standard *P*-value of < 0.05. All statistical analyses were performed using *R* statistical software. Charts were reviewed and analyzed by two independent researchers to ensure accuracy and consistency.

## RESULTS

A total of 60 patient charts met inclusion and exclusion criteria, with 43 patients in the conventional group and 17 patients in the navigated group. The study included 26 women and 34 men. The age of patients in the study group ranged from 12 years of age to 82 years of age, with an expected bimodal distribution (Figure 1). BMI values ranged from 15 to 49. There was no significant difference in the number of screws placed per patient between the two groups (*P* = 0.85).

### Radiation Time

There was a statistically significant difference in total radiation time between the two techniques. The conventional fluoroscopy group demonstrated higher average and median total radiation time compared to the 3D navigated fluoroscopy technique (*P* < 0.001). This difference persisted when evaluating radiation time per number of screws placed, with the conven-

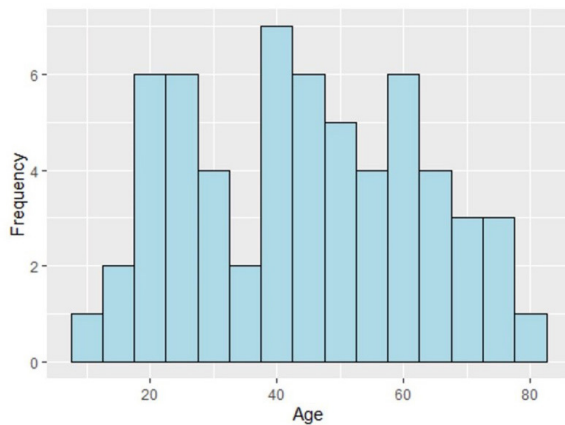
tional group showing higher median radiation time per screw (39.2 seconds) compared to the 3D navigated group (19.5 seconds) ( $P < 0.001$ ).

### Radiation Dose

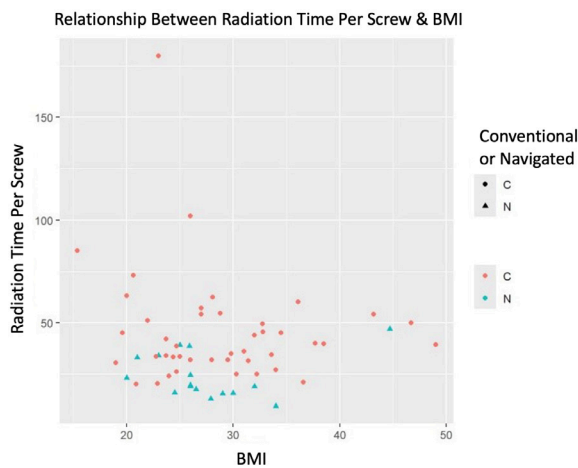
No significant difference in total radiation dose was observed between the conventional (88.52 mGy) and 3D navigated (78.2 mGy) fluoroscopy groups ( $P = 0.40$ ). There remained no difference when comparing radiation dose per screw between the conventional (42.23 mGy) and navigated (38.49 mGy) groups ( $P = 0.62$ ).

### Surgical Duration

The surgical duration did not differ significantly between the conventional fluoroscopy and 3D navigated techniques ( $P = 0.24$ ). No difference was observed when comparing surgical duration per screw between the two groups, with the conventional group demonstrating a median of 35.25 minutes per screw and the 3D navigated group demonstrating a median of 39.25 minutes per screw ( $P = 0.62$ ).



**Figure 1.** Demographic data showing the expected bimodal age distribution of pelvic ring injuries requiring surgical fixation.



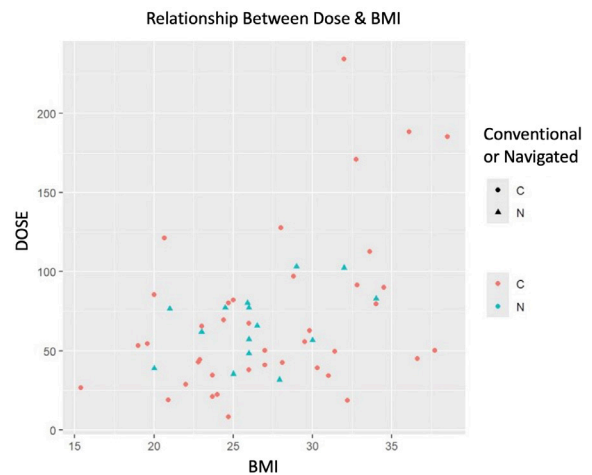
**Figure 3.** Radiation time per screw clusters around a lower value for the navigated technique when compared to conventional technique. There is no correlation between radiation time per screw and BMI.

### Correlation with Patient Factors

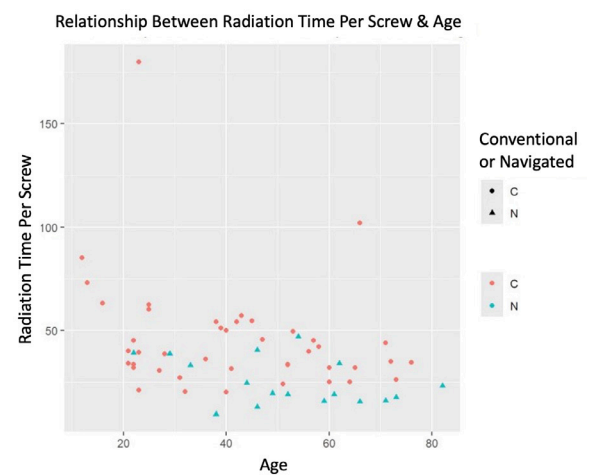
Further analysis of the data revealed a strong positive correlation between radiation dose and BMI ( $R = 0.68$ ,  $P < 0.001$ ) (Figure 2). This correlation was observed in both the conventional ( $P < 0.001$ ) and navigated ( $P < 0.001$ ) groups. However, no significant correlation was found between BMI and either radiation time per screw ( $P = 0.50$ ) or surgical duration per screw ( $P = 0.95$ ) (Figure 3).

There was a slight negative correlation between radiation time per screw and age ( $P = 0.011$ ) (Figure 4). This correlation was observed in both the conventional ( $P = 0.11$ ) and navigated ( $P = 0.12$ ) groups. However, no significant correlation was found between surgical duration per screw and age ( $P = 0.16$ ).

Given the demonstrated relationship between radiation dose and BMI, the authors performed a sub-analysis excluding patients with a BMI greater than 40 to limit the effect of this potential confounder. This excluded a



**Figure 2.** Positive correlation between radiation dose and BMI shown in both the conventional and navigated groups.



**Figure 4.** Negative correlation between radiation time per screw and age. The navigated group clusters around a lower radiation time per screw, but both groups demonstrate the slight negative correlation.

total of four patients. The results of the repeat analysis showed no change in the outcome data. The conventional group continued to demonstrate increased radiation time and radiation time per screw compared to the navigated group. However, there remained no significant differences in radiation dose, surgery time, or surgical duration per screw between the two groups. Thus, the exclusion of patients with a BMI greater than 40 did not meaningfully affect the outcomes of this analysis.

### **Summary of Results**

In summary, while conventional fluoroscopy resulted in higher total radiation time compared to 3D navigated fluoroscopy, no significant differences were found between the two techniques in terms of radiation dose or surgical duration per screw. A positive correlation between radiation dose and BMI was observed, but this did not affect the overall comparison between the two fluoroscopic techniques. Excluding patients with a BMI greater than 40 did not alter the findings.

## **DISCUSSION**

To perform safe SI screw fixation, surgeons must understand complex pelvic and sacral anatomy, including distinct variations, and be able to reliably obtain and interpret intraoperative imaging. Anatomical challenges are common, as the upper sacrum has a high degree of variability in shape, rendering image interpretation difficult.<sup>12</sup> Sacral dysmorphism, described as a narrowed or nonexistent trans-sacral corridor through the first sacral segment, is a common variant of sacral morphology with an incidence of 11.0% to 44.0% in the general population.<sup>13</sup> Patients with sacral dysmorphism undergoing SI or trans-sacral screw fixation are at increased risk for cortical penetration and nerve injury.<sup>10,13</sup> These anatomical realities underscore the need for reliable imaging during surgical fixation.

The conventional technique of SI screw fixation is technically complex. It is heavily dependent on both the fluoroscopic technician and the surgeon's ability to interpret the fluoroscopic images, while simultaneously controlling wire placement.<sup>12</sup> Static fluoroscopic images are obtained from the inlet, outlet, and lateral projection views of the pelvis to identify anatomical landmarks and guide the placement of wires or drills.<sup>12</sup> The image intensifier can only visualize one plane at a time.<sup>10</sup> The rate of incorrect SI screw placement using this technique is estimated to range from 2.0% to 15.0%.<sup>1</sup>

In contrast, navigated 3D imaging is a technique that uses an intraoperative 3D fluoroscopic scan. A navigation tracker is placed on a fixed bony landmark near the surgical anatomy of interest, and a computed tomography (CT) scan is performed. The resulting images are transmitted to a navigation workstation, where they are used to register and label surgical instruments in 3D space. After registration, guide wires,

drill guides, cannulated drill bits, and screws are placed in the desired corridor under navigated guidance aligned with the intraoperative scan.

Navigation systems were introduced for spine and pelvic surgery to improve precision and accuracy in screw placement.<sup>7</sup> Theoretical benefits include excellent image quality, greater regional view of the pelvis, and reduced metal artifact.<sup>7</sup> Some studies suggest that CT-guided screw placement is more accurate and associated with lower radiation doses.<sup>7,12,14</sup> However, other studies report that navigation may result in equal or even increased radiation exposure.<sup>14</sup> This discrepancy is likely due to variations in study design and the type of navigation system used (eg, preoperative CT, intraoperative CT, O-arm, etc).

In this study, the radiation time required for SI fixation was significantly higher in the conventional group compared to 3D navigated group. However, the authors found no significant difference in total radiation dose or radiation dose per screw. These findings are likely explained by the differences in how images are obtained between the two techniques. The 3D navigated fluoroscopic scan is brief but requires higher radiation doses to penetrate soft tissues, particularly when imaging in the oblique planes needed to complete a "spin." This results in a fluoroscopic study that is shorter in time but similar in overall dose.

While an equivalent radiation dose result supports the noninferiority of the navigated technique, another critical consideration is the physical positioning of the surgical team during radiation exposure. During the preoperative 3D scan in the navigated technique, the medical staff is generally positioned more than six feet away from the scanner, behind additional radiation protective equipment, or even outside the OR entirely. This contrasts with the conventional technique, where surgeons and support staff are positioned directly next to the C-arm during live fluoroscopy. As such, while the overall radiation dose to the patient is equivalent between the two techniques, the radiation exposure to surgical staff is significantly lower in the 3D navigated technique. Radiation exposure to surgical staff is under-studied in the existing literature, and use of the 3D navigated technique could substantially decrease lifetime radiation exposure and associated health risks.<sup>10,15</sup>

Another benefit of the 3D navigated technique is that it does not rely on live imaging, making it less susceptible to real-time issues that impair visualization, such as poor bone quality, transitional anatomy, increased bowel gas, or inconsistent C-arm positioning. Once the scan images are obtained, surgeons or trainees can work in fixed horizontal and vertical planes, as opposed to working orthogonally to the variable inlet and outlet angles of the conventional C-arm. However, this lack of

reliance on live imaging also creates a static environment, which can limit flexibility, especially during fracture reduction. If bony fragments are displaced during reduction, a repeat fluoroscopic scan is required to re-register the new bony positions before implants can be safely adjusted.

The authors also hypothesized that surgical duration would be shorter in the navigated technique compared to the conventional technique. However, the literature on this topic is conflicting, with evidence showing no difference, as well as both longer and shorter durations when navigation is applied.<sup>14</sup> The novelty and experience of surgeons using navigated techniques may contribute to this lack of consensus. This study demonstrated no statistical significance in surgical duration or surgical duration per screw between the two techniques. These results support the noninferiority of the navigated technique in terms of surgical timing and efficiency when performed by experienced surgeons. The study also reaffirmed the clear correlation between radiation dose and BMI, a well-recognized phenomenon in pelvic surgery. This correlation persisted when analyzing the data for the conventional and navigated groups separately, suggesting no advantage for either technique in patients with a high BMI.

Limitations of this study include its observational nature and relatively small sample size. A difference may have been detected if more navigated cases had been performed. The study is also limited by the lack of outcomes related to screw and patient clinical outcomes – two factors that are more likely to inform clinical decision between the two techniques.

In summary, when comparing conventional versus 3D navigated SI screw fixation, the conventional fluoroscopy technique required more radiation time with a similar overall dose. The 3D navigated technique did not increase surgical duration and offered a clear benefit in terms of radiation exposure to OR staff given their positioning during imaging. The authors reaffirmed a positive correlation between radiation dose and BMI. Ultimately, there are benefits to both conventional and 3D navigated techniques, and this study supports noninferiority on most measures. It is likely best practice for surgeons to be proficient in both techniques, enabling them to choose the most appropriate one based on clinical scenarios. Further research on screw positioning and patient outcomes is needed to more definitively determine if one technique is truly superior.

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