

Determination of the best point of entry of percutaneous insertion of sacroiliac screws depending on patient positioning for surgery: A cadaveric study

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D – writing the article; E – critical revision of the article; F – final approval of the article

Advances in Clinical and Experimental Medicine, ISSN 1899–5276 (print), ISSN 2451–2680 (online)

Adv Clin Exp Med. 2025;34(4):613–621

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Funding sources

None declared

Conflict of interest

None declared

Received on September 23, 2023

Reviewed on January 28, 2024

Accepted on May 15, 2024

Published online on August 1, 2024

Cite as

Kułakowski M, Elster K, Piotrowski W, et al. Determination of the best point of entry of percutaneous insertion of sacroiliac screws depending on patient positioning for surgery: A cadaveric study. *Adv Clin Exp Med.* 2025;34(4):613–621. doi:10.17219/acem/188780

DOI

10.17219/acem/188780

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Abstract

Background. The standard starting point for percutaneous sacroiliac screw insertion was initially determined at the intersection of the line posterior to the anterior superior iliac spine and the line continuing the anatomical axis of the femur. The technique was pioneered in patients lying prone in surgery, although it has been used with patients in the supine position. The optimal starting point for patients in both prone and supine positions remains uncertain.

Objectives. This cadaveric study aimed to determine the best entry point for the percutaneous insertion of sacroiliac screws depending on the patient's positioning for surgery.

Materials and methods. Kirschner wires (K-wires) were percutaneously inserted into the sacral body of 8th human cadavers. In addition to the so-called standard sacroiliac screw entry point (point A), points located consecutively 1 cm (point B) and 2 cm (point C) cranially from the point along the line, prolonging the femoral axis were also studied. The K-wires were inserted into the studied entry points on the right side in a supine position and on the left side of the same cadaver in a prone position. The placement of the K-wires was assessed using radiographic imaging and cadaver dissection.

Results. An analysis of the K-wire placement in the supine position revealed incorrect positioning of 100% of the K-wires inserted at entry point A and 87% at entry point B. All the K-wires inserted in the supine position at entry point C were correctly placed. All K-wires inserted in the prone position were correctly positioned.

Conclusions. All 3 studied entry points enabled the correct placement of orthopedic implants for prone position surgery. The best entry point for surgery performed in the supine position was located 2 cm cranially from the standard entry point, along the line prolonging the femoral axis.

Key words: fracture fixation, pelvis, traumatology

Background

Pelvic fractures, one of the most severe and life-threatening traumatic injuries, constitute approx. 1.5–3% of all skeletal fractures.^{1,2} Of these, around 40% are unstable because of posterior pelvic ring disruption,³ which may or may not be associated with severe trauma.^{4,5} While not considered frequent, sacroiliac joint injuries are associated with significant morbidity and mortality.^{6–12}

The advantages of surgical treatment for unstable pelvic fractures over nonsurgical treatment have been well-known for the last 30 years, including increased effectiveness in fracture reduction, earlier weight-bearing and mobilization, lower mortalities, shorter hospital stays, and generally better functional outcomes.^{11,13–16} The standard technique for surgical fixation of the sacroiliac joint used to be an open reduction and internal fixation (ORIF) using sacral bars or posterior plating. Yet, a minimally invasive approach that reduces the risk of wound infection and blood loss and provides relatively good fracture fixation strength using percutaneously inserted sacroiliac screws was introduced by Matta and Saucedo and is now a commonly used treatment for pelvic ring injuries, replacing open procedures.^{17–20}

However, incorrect placement of the sacroiliac screws may cause severe complications, including iatrogenic injuries of large vessels and nerves and loss of fixation.^{16,21} Therefore, intraoperative visualization with conventional fluoroscopy remains the current standard in most hospitals. In addition, computed tomography, fluoroscopic computed tomography and computer-assisted techniques have also been utilized.^{22–25} Some authors propose digital 3-dimensional navigation printing to minimize complications arising from sacroiliac screw misplacement.²⁶

The starting point for the percutaneous sacroiliac screw insertion initially defined by Matta and Saucedo is located 15 mm anterior to the gluteal crest at a point 50% of the distance between the greater sciatic notch and the iliac crest, which corresponds to the intersection of the line posterior to the anterior superior iliac spine and the line that is a continuation of the anatomic axis of the femur.¹⁸ The technique was pioneered in patients in the prone position but has been modified and used with patients in the supine position.¹⁹ Whether the starting point for percutaneous sacroiliac screw insertion determined by Matta and Saucedo is an appropriate entry point for patients in prone and supine surgical positions remains unknown.

Unfortunately, the literature is also sparse regarding research on the development of new methods, including new entry points of percutaneous sacroiliac screw insertion, which could be more effective in terms of safety and time of the surgery. In their 2018 cadaveric study, Javidmehr et al.²⁷ demonstrated a new iliosacral screw insertion method that was found to be safer and faster to implement than its conventional counterpart. Both modified and conventional methods were similar regarding the safety index for distance

from the anterior cortex and 1st sacral vertebra (S1) foramen. However, the new modified method was also found to be safer in terms of the distance from the sacral canal. Additionally, the method introduced by Javidmehr et al. was easier and faster to implement than the conventional method. Neither method penetrated the sacral canal, anterior cortex and S1 foramen during guidewire insertion,²⁷ although the study was carried out only for 1 surgical positioning.

Objectives

The present cadaveric study aimed to determine the best entry point for the percutaneous insertion of sacroiliac screws depending on the patient's positioning for surgery.

In the context of a cadaveric study, it was hypothesized that the choice of the best point of entry for percutaneous sacroiliac screw insertion is influenced by the positioning of the cadaver during the procedure. It was postulated that variations in cadaveric positioning would impact the accuracy of screw placement, with specific positions demonstrating superior precision and reduced variability. Through examination of different entry points for 2 surgical positions, it was anticipated to identify a preferred point of entry that maximizes the correctness of sacroiliac screw fixation, thus providing valuable insights for optimizing surgical outcomes in clinical practice.

Materials and methods

The study was conducted in the laboratory of a medical institute. The pelvic preparations were brought to the institute in a lawful manner and with the knowledge of the Polish Ministry of Health. In the present study, informed consent was obtained prior to the donors' deaths through a body donation program, where individuals voluntarily agreed to donate their bodies for scientific research and education. The authors of the paper obtained written consent from the institute for using unfixed human pelvic preparations for research and scientific purposes of the current project. In addition, the authors obtained written permission to publish the photographs in the present article. The study was carried out according to the Declaration of Helsinki as the ethical standard for research involving human biological material and approved by the Kuyavian-Pomeranian Local Medical Chamber (approval No. 21/KB/2022).

The studied material consisted of 8 adult, fresh-frozen, full-body cadavers of 3 men and 5 women with a mean age at death of 68.00 ± 2.00 years. None of the cadavers demonstrated subjective osteopenia. Additionally, none of the cadavers was identified as having sacral dysmorphism, and none had undergone pelvic surgery during their lifetime or had fractures in the pelvic area. Each cadaver was thawed at room temperature overnight before being used for study purposes.

Percutaneous Kirschner wire insertion

Initially, 3 Kirschner wire (K-wire) entry points were marked bilaterally. The 1st was a standard starting point for the sacroiliac screw, initially defined by Matta and Saucedo, located at the intersection of the line posterior to the anterior superior iliac spine and the line that is a continuation of the anatomic axis of the femur.¹⁸ For this study it was named point A. Entry point B was placed 1 cm cranially from entry point A along the line, prolonging the anatomical femoral axis. Entry point C was situated 1 cm cranially from entry point B and 2 cm cranially from entry point A along the line, prolonging the anatomical femoral axis. The 3 K-wires were percutaneously inserted into the sacral body at the 3 consecutive entry points on the right side of a cadaver in a supine position (Fig. 1).

Next, the 3 K-wires were inserted into consecutive entry points on the left side of the same cadaver, set in a prone position. The wires were inserted under conventional C-arm fluoroscopy (C-arm Cios Flow; Siemens AG, Munich, Germany). The insertion procedure for all cadavers was performed by the same specialist in orthopedics and traumatology, who has many years of experience in pelvic surgery.

Radiographic imaging and cadaver dissection

The placement of the inserted K-wires in the sacral bone was assessed using radiographic imaging and cadaver dissection. A radiograph was performed supine to visualize

the pelvis in the inlet view using C-arm, the inserted K-wires in the supine position on the right side and those inserted in the prone position on the left side. The inserted distance of the K-wires from the medial axis of the sacrum was assessed in the inlet view and expressed in millimeters. A negative value meant that the inserted K-wire was posterior to the medial axis, while 0 indicated insertion along the medial axis. A positive value indicated that the inserted K-wire was placed anterior to the midline of the sacrum. All radiographs were analyzed by a single specialist in orthopedics and traumatology, who has extensive experience in pelvic surgery. Subsequently, cadaver dissection was performed. In cases where the K-wire was not seen to penetrate the pelvis, the penetration distance was indicated as 0 mm, meaning that the inserted K-wire was entirely within the bone. In other cases, the distance between the K-wire and the margin of the cortex of the sacrum was measured with a ruler and expressed in mm (Fig. 2). The same highly experienced specialist performed all cadaver dissections.

Statistical analyses

The statistical analysis was performed using IBM SPSS Statistics Premium v. 28 (IBM Corp. Armonk, USA), and Microsoft Office Excel 365 (Microsoft Corp., Redmond, USA). As the study included fewer than 10 samples, non-parametric tests were used.

The median (Me), 1st quartile (Q1) and 3rd quartile (Q3) were calculated for the measured distances between the K-wire and the transverse axis of the sacrum in radiographic

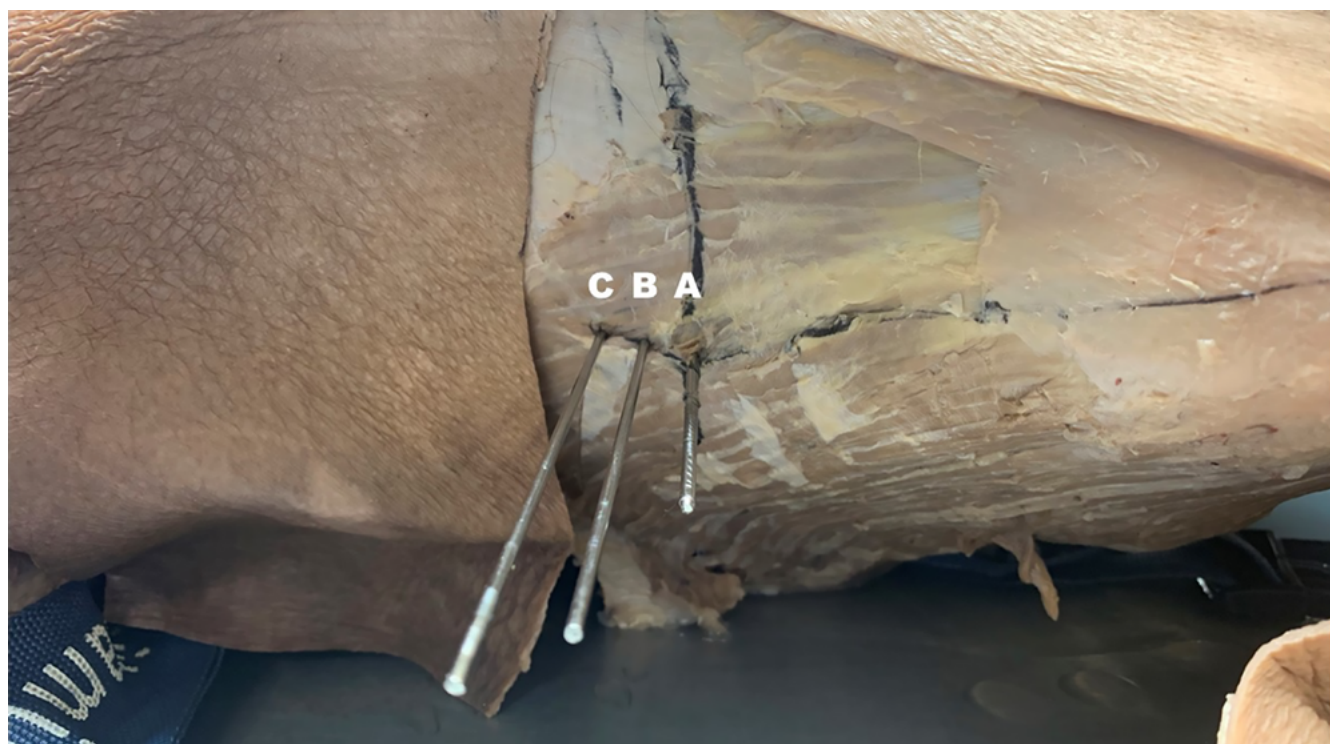


Fig. 1. Percutaneously inserted Kirschner wires on the right side of the cadaver in a supine surgical position at the 3 consecutive entry points, namely, point A, point B and point C



Fig. 2. Picture of the dissection of 1 of the studied cadavers

inlet view images and between the K-wire and the sacral bone anterior cortex in cadaver dissection. The Friedman's test was used to compare distances between K-wires inserted in the 3 consecutive entry points.

If the Friedman's test yielded a significant result, indicating differences among the dependent groups, Wilcoxon signed-rank post hoc tests were conducted to identify which specific pairs of groups differ significantly. To correct for multiple comparisons, the desired significance level, precisely 0.05, was divided by the number of comparisons being made, precisely 3, resulting in a corrected significance level of approx. 0.017.

Correct placement of the K-wire inserted using a particular entry point for the supine and prone surgical positions was defined when the wire was located entirely within the sacral cortical boundaries. When the K-wire was not entirely within the sacral bone, its placement was determined as incorrect. The Cochran's Q test and, consecutively, McNemar's test were used for the comparison of the number of cadavers with correctly inserted K-wires at the particular entry points separately for supine and prone positions. Bonferroni correction for multiple corrections was applied. Statistical significance was set at $p < 0.050$.

Results

Kirschner wires inserted in the supine surgical position

Detailed analysis of the distances between the K-wires inserted in the supine position and the midline (inlet view) or margin of the cortex (cadaver dissection) of the sacral bone was presented in Table 1.

The performed Friedman's test revealed statistically significant differences ($\chi^2(2) = 15.548$, $p < 0.001$) between K-wires inserted in the 3 consecutive entry points in the supine position in terms of measured distances between the K-wires and the transverse axis of the sacrum in radiographic inlet view images. Moreover, in terms of distances measured during cadaver dissection between the K-wires and the margin of the sacral bone, the Friedman's test revealed statistically significant differences between the 3 studied entry points ($\chi^2(2) = 15.200$, $p < 0.001$).

Consecutively performed Wilcoxon signed-rank tests revealed that for the K-wires inserted percutaneously in the supine position in entry point C, the median distance between the wires and the midline of the sacral bone in the inlet view was significantly smaller than those inserted in entry point A ($Z = -2.527$, $p = 0.012$) and entry point B ($Z = -2.539$, $p = 0.011$) (Table 2).

The results of the Wilcoxon signed-rank test also revealed that the distance between the K-wires inserted

Table 1. Comparison between the 3 studied entry points in terms of distance between the Kirschner wires inserted in the supine position and the midline (inlet view) or margin of the cortex (cadaver dissection) of the sacral bone (Friedman's test results)

Insertion entry point		Inlet view			Cadaver dissection		
		Me	Q1	Q3	Me	Q1	Q3
Entry point A		11.50	10.25	12.75	6.50	5.25	7.75
Entry point B		7.00	6.00	8.00	1.00	0.25	2.00
Entry point C		1.00	0.00	1.75	0.00	0.00	0.00
Friedman's test results	χ^2	15.548			15.200		
	df	2			2		
	p-value	<0.001			<0.001		

Values are expressed as the median (Me), the 1st quartile (Q1) and the 3rd quartile (Q3); df – degrees of freedom. Statistically significant p-values are in bold.

in the supine position and the margin of the sacral bone was significantly larger ($Z = -2.530$, $p = 0.011$) than for the wires inserted in entry point A than in entry point B (Table 2). Because no K-wires inserted in entry point C were outside the bone during the cadaver dissections, the Wilcoxon signed-rank test revealed significantly larger distances between the K-wires inserted in the supine position in entry point A ($Z = -2.527$, $p = 0.012$) and the margin of the sacral bone.

Kirschner wires inserted in the prone surgical position

The radiographic analysis of the inlet view revealed the most profound penetration for the K-wires inserted in entry point A (Table 3). The negative median values obtained on inlet views for K-wires inserted in entry points B and C indicate that the wires were entirely within the bone and posterior to the midline of the sacrum.

The Friedman's test revealed statistically significant differences ($\chi^2(2) = 16.000$, $p < 0.001$) between K-wires inserted in the 3 consecutive entry points in the prone position in terms of distances measured between the K-wires and the transverse axis of the sacrum in radiographic inlet view images. The Wilcoxon signed-rank test revealed that the penetration for the K-wires inserted in entry point A was significantly larger than for the K-wires inserted in entry point B ($Z = -2.640$, $p = 0.008$) and entry point C ($Z = -2.588$, $p = 0.010$) (Table 4).

During the cadaver dissections, no K-wires inserted in entry points A, B or C were outside the bone.

Percentage of cadavers with correctly placed Kirschner wires

In all of the studied cadavers, the radiographic analysis of the inlet view revealed the incorrect placement of K-wires inserted in the supine position at entry point A

Table 2. Comparison between the 3 studied entry points in terms of distance between the Kirschner wires inserted in the supine position and the midline (inlet view) or margin of the cortex (cadaver dissection) of the sacral bone (Wilcoxon signed-rank test results)

Compared entry points	Wilcoxon signed-rank test's results			
	inlet view		cadaver dissection	
	Z	p-value	Z	p-value
Entry points A vs B	-2.388	0.017	-2.530	0.011
Entry points A vs C	-2.527	0.012	-2.527	0.012
Entry points B vs C	-2.539	0.011	-2.232	0.026

Statistically significant p-values are in bold.

Table 3. Comparison between the 3 studied entry points in terms of distance between the Kirschner wires inserted in the prone position and the midline (inlet view) or margin of the cortex (cadaver dissection) of the sacral bone (Friedman test results)

Insertion entry point		Inlet view			Cadaver dissection		
		Me	Q1	Q3	Me	Q1	Q3
Entry point A		1.00	0.00	2.00	0.00	0.00	0.00
Entry point B		-1.50	-2.00	0.00	0.00	0.00	0.00
Entry point C		-4.00	-4.75	-3.25	0.00	0.00	0.00
Friedman's test results	χ^2	16.000			N/A		
	df	2			N/A		
	p-value	<0.001			N/A		

Values are expressed as the median (Me), the 1st quartile (Q1), and the 3rd quartile (Q3); df – degrees of freedom; N/A – not applicable. Statistically significant p-values are in bold.

Table 4. Comparison between the 3 studied entry points in terms of distance between the Kirschner wires inserted in the prone position and the midline (inlet view) or margin of the cortex (cadaver dissection) of the sacral bone (Wilcoxon signed-rank test results)

Compared entry points	Wilcoxon signed-rank test's results			
	inlet view		cadaver dissection	
	Z	p-value	Z	p-value
Entry points A vs B	-2.640	0.008	N/A	N/A
Entry points A vs C	-2.588	0.010	N/A	N/A
Entry points B vs C	-2.588	0.010	N/A	N/A

N/A – not applicable. Statistically significant p-values are in bold.

and entry point B (Fig. 3). In contrast, the correct placement of K-wires inserted in the supine position at entry point C was observed in 38% of the cadavers. Using the Q Cochran test, our results demonstrated significant differences ($Q(2) = 6.00$, $p = 0.050$) between the number of correctly placed K-wires determined on the radiographic analysis of the inlet view inserted in the 3 entry points (Table 5).

Consecutive comparisons are presented in Table 6. The final analysis of the placement of K-wires during

cadaver dissection revealed no correct positioning of any of the K-wires inserted at entry point A in the supine position (Fig. 4). In 13% of cadavers, we noted the correct placement of K-wires inserted in the supine position at entry point B. All K-wires inserted in the supine position at entry point C were correctly placed.

The radiographic analysis of the inlet view determined that the percentage of cadavers with correctly placed K-wires inserted in the prone position at entry points

Table 5. Comparison between the three studied entry points in terms of distance of the correctness of placement of the inserted Kirschner wires in the sacral bone (the results of Cochran's Q test).

Surgical positioning		Insertion in supine position		Insertion in prone position	
compared entry points		inlet view	cadaver dissection	inlet view	cadaver dissection
Entry point A		0/8	0/8	3/5	8/0
Entry point B		0/8	2/6	7/1	8/0
Entry point C		3/5	8/0	8/0	8/0
Cochran's test results	Q	6.00	13.00	8.40	N/A
	df	2	2	2	N/A
	p-value	0.050	0.002	0.015	N/A

Values are expressed as a number of cadavers with correct/incorrect placement; N/A – not applicable. Statistically significant p-values are in bold.

Table 6. Comparison between the 3 studied entry points in terms of distance of the correctness of placement of the inserted Kirschner wires in the sacral bone (the results of McNemar's test)

Surgical positioning		Insertion in supine position		Insertion in prone position	
compared entry points		inlet view	cadaver dissection	inlet view	cadaver dissection
Entry points A vs B		N/A	$p = 0.386$ $p = 1.000^*$	$p = 0.028$ $p = 0.085^*$	N/A
Entry points A vs C		$p = 0.034$ $p = 0.102^*$	$p < 0.001$ $p = 0.002^*$	$p = 0.006$ $p = 0.019^*$	N/A
Entry points B vs C		$p = 0.034$ $p = 0.102^*$	$p = 0.009$ $p = 0.028^*$	$p = 0.584$ $p = 1.000^*$	N/A

Values expressed as McNemar's test results. N/A – not applicable. *Bonferroni correction for multiple corrections. Statistically significant p-values after providing Bonferroni correction are in bold.

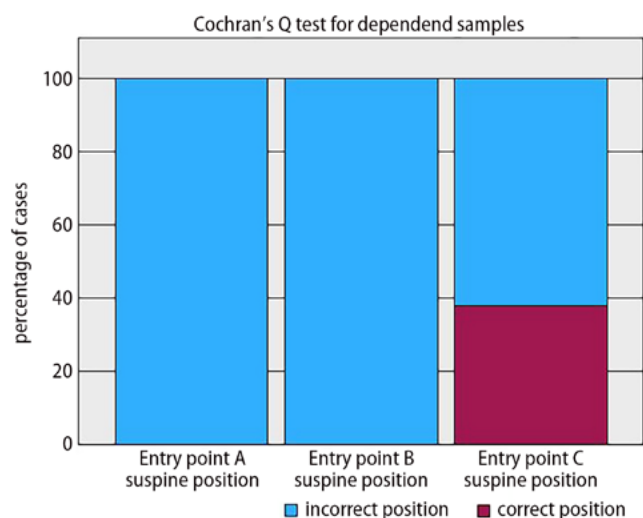


Fig. 3. Analysis of the percentage of cadavers in which correct and incorrect Kirschner wire placement was observed on radiographic imaging in the inlet view at particular entry points in the supine surgical position

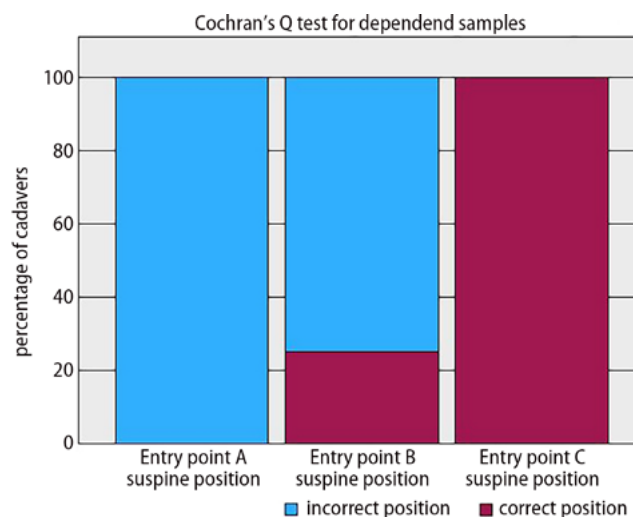


Fig. 4. Analysis of the percentage of cadavers in which correct and incorrect Kirschner wire placement was observed during cadaver dissection at particular entry points in the supine surgical position

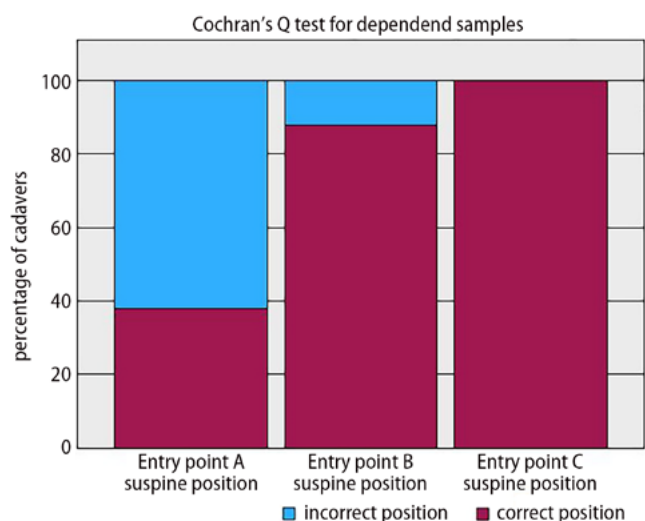


Fig. 5. Analysis of the percentage of cadavers in which correct and incorrect Kirschner wire placement was observed on radiographic imaging in the inlet view at particular entry points in the prone surgical position

A, B, and C exceeded 38%, 88% and 100%, respectively (Fig. 5), and Tables 5,6 present detailed comparisons. The cadaver dissection revealed that all the K-wires inserted in the prone position were in the correct position regardless of the insertion entry point.

Discussion

This cadaver study demonstrated that the best entry points for percutaneous insertion of sacroiliac screws are different for surgeries performed in the prone and supine positions. The standard entry point, initially defined by Matta and Saucedo, and points located 1 cm and 2 cm cranially from the mentioned standard point along the line prolonging the femoral axis enabled the correct placement of orthopedic implants for surgery performed in the prone position. Moreover, the best entry point for surgery performed in the supine position was located 2 cm cranially from the mentioned standard entry point along the line extending the femoral axis.

Percutaneous sacroiliac-screw fixation is considered the gold standard when it comes to the treatment of posterior pelvic ring fractures. It was developed as an alternative to the previous ORIF technique. Unfortunately, it had a high risk of extensive dissections, prominent implants, iatrogenic injuries, infection, and blood loss in already traumatized patients.^{11,16,28–30} Sacroiliac screws are multipurpose and can be used to treat a variety of sacral fractures or sacroiliac joint dislocations.¹⁶ They are utilized to stabilize pelvic ring injuries using a corridor of bone through the ilium, sacroiliac joint, sacral ala, and sacral promontory.³¹

The sacroiliac screws can be inserted in a supine, prone or lateral position.¹⁶ Initially, the starting point for the percutaneous sacroiliac screw insertion, as defined by Matta and Saucedo, is located 15 mm anterior to the gluteal crist

at 50% of the distance between the greater sciatic notch and the iliac crest.¹⁸ It corresponds to the intersection of the line posterior to the anterior superior iliac spine and the line that continues the anatomic axis of the femur.¹⁸ Ebraheim et al. determined the starting point for the sacroiliac screw on the outer table of the ilium 3 cm anterior to the posterior superior iliac spine and 4 cm cephalad to the greater sciatic notch.³² While Matta and Saucedo determined the best entry point for percutaneous sacroiliac screw fixation in patients operated in the prone position,¹⁸ Routt et al. subsequently used the same entry point for surgeries performed on patients in the supine position.¹⁹ However, no studies have examined the adequacy of the same entry point for patients in prone and supine surgical positions. The present cadaver study indicated that the best entry points for percutaneous insertion of sacroiliac screws are different for surgeries in the prone and supine positions. While the standard entry point, as defined by Matta and Saucedo, was adequate for correctly placing sacroiliac screws into cadavers in the prone position, it was ineffective for surgeries performed in the supine position.

The most effective entry point for the correct placement of sacroiliac screws in cadavers in the prone position was determined to be located 2 cm cranially from Matta and Saucedo's entry point along the line extending the femoral anatomic axis. This finding is crucial for clinical practice, as placing a patient in a supine position is required for anterior pelvic ring stabilization. Hence, using the best entry point for surgeries performed in the supine position eliminates the need to change the patient's position intraoperatively from supine to prone.

Despite its many advantages, percutaneous sacroiliac screw fixation presents a considerable risk of iatrogenic injuries.¹⁶ Sacroiliac screw placement also carries a risk of neurovascular structure injuries, including to the L5 and S1 nerve roots. However, the superior gluteal neurovascular bundle may also be injured by percutaneously inserted sacroiliac screws.^{33,34} Furthermore, the superior gluteal artery and iliac vessels are at risk of injury,¹⁶ and screw malposition rates can be up to 25%.³⁵ Therefore, various imaging modalities are used to support the insertion. Preoperative planning and understanding of sacroiliac screw placement are crucial to minimizing the occurrence of complications.

Limitations

This study has several limitations. First, it should be highlighted that none of the studied cadavers had sacral dysmorphism. In other words, the best entry points were determined for normal sacral anatomy. Variations in the normal sacral anatomy, including angulated upsloping ala and incomplete upper sacral segment disc space defined as sacral dysmorphism, occur at a relatively high incidence of 20–40%.^{23,24} Because patients may have different anatomies, preoperative and intraoperative imaging is crucial

to maintain their safety.²³ In combination with anteroposterior, inlet and outlet views, lateral sacral images are required for intraoperative visualization. Second, the sample size was small, and a larger sample may allow a more decisive conclusion. A 3rd limitation of the present study is its design, with clinical studies being needed to investigate whether the best entry points that theoretically improve surgical accuracy translate into better clinical outcomes.

Conclusions

The cadaver study showed that the best entry points for percutaneous insertion of sacroiliac screws are different for surgeries in the prone and supine positions. The standard entry point, initially defined by Matta and Saucedo, and points located 1 cm and 2 cm cranially from the mentioned standard point along the line extending the femoral axis enabled the correct placement of orthopedic hardware for surgery performed in the prone position. However, the best entry point for surgery performed in the supine position was located 2 cm cranially from the mentioned standard entry point, along the line prolonging the femoral axis.

Data availability statement

All data generated and analyzed during this study are included and available to the readers as they were deposited in an online repository (<https://doi.org/10.5281/zenodo.8357116>).

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