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CT-based Anatomic and Clinical Analysis of Iliac Screw Placement During Spinopelvic Fixation

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Abstract

Background/Aim: Iliac screws provide strong caudal anchorage for both long spinal fusions as well as short lumbopelvic fixations. However, anatomic based placement can be challenging, and complication rates are often underestimated.

Patients and Methods: We analysed 47 iliac screws being placed in 24 patients. Using postoperative computed tomography (CT), iliac screw placement was analysed with reference to anatomic landmarks. Iliac narrowings were described with regard to their relevance for iliac screw placement. Moreover, we analyzed clinical records for clinical complications. The latter were classified as intraoperative, postoperative, and radiological.

Results: From starting points, described by distance to the posterior superior iliac spine (PSIS), the average iliac screw length was 71.2±13.7 mm, and the diameter was as wide as 7.9±0.7 mm. Divergence was 30.7±12.6˚ (transverse plane) and caudal orientation was 34.2±13.0˚ (sagittal orientation). General pelvic dimensions correlated significantly with each other, and certainly with the length of implanted screws. Different adverse events and complications occurred. A total of 20% of patients were found with at least partial extracortical malpositioning. The main group of complications were postoperative with painful prominence in 20% of cases, wound infection in 8.9% and wound healing disorders in 6.7%. Further complications were radiological screw loosening (11.1%). No complications were detected in 33.3% of patients.

Conclusion: Optimal iliac screw size relative to the individual anatomy in general is not achieved. In most cases compared to the literature, iliac screw dimensions could be both longer and thicker. Perfect anatomic placement can be challenging, which highlights the need for individual preoperative CT-based surgical planning to achieve a strong caudal anchorage in lumbopelvic fixations. In general, the diameter seems to be more important than the screw length.

Keywords: Lumbopelvic fixation, iliac screw placement, spinopelvic fixation, iliac screw.

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Introduction

Lumbopelvic fixation is used for several indications such as trauma, tumor, deformity realignment surgery, infectious causes or degenerative diseases. It provides strong distal anchorage (1, 2). Fixation at the pelvis, also being accepted at the basement of the spine, can best be achieved using S2AI (S2 alar-iliac) screws or iliac screws. While S2AI screws offer different advantages, *i.e.,* being beneficial during rod bending, iliac screws are accepted to be biomechanically strongest and the most favourable option with highest pull-out forces being needed (3). Moreover, iliac screws are the only distal option for screw placement in some indications like sacral fractures or in sacral resections due to tumors (4).

Preoperative computed tomography (CT) should be mandatory for planning purposes since it is also used for diagnostic purposes (1). As in any orthopaedic surgery, correct implant dimensions and optimal screw fixation are crucial. Schildhauer *et al.* first intensively studied anatomic based optimization of iliac screw dimensions relative to anatomic iliac wing dimensions with the starting point at posterior superior iliac spine (PSIS). They found that a screw diameter, at least as high as 8 mm (for males) and 6-7 mm (for females) as well as a minimum screw length of 100 mm were anatomically possible for best distal anchorage (5). According to Schildhauer *et al*. two constrictions limit the maximum iliac screw diameter. Constriction 1 (C1) will be reached after ~33 mm (males) or ~27 mm (females), with a maximum inner width (IWC1) of ~12 mm (males) and ~9 mm (females). The constriction 2 (C2) was published to be reached after an average of 86 mm (males) or 84 mm (females) and had an inner width of approximately 15 mm (males) and 11 mm (females), all distances referring to the posterior superior iliac spine (5).

Optimal pull-out strength is dependent on the implant-bone-interface. For pedicle screws, 55-58% of implant-bone-interface have been published to be sufficient (6). It must be emphasized that pull-out strength of pedicle screws is mostly determined in the vertebral pedicle, and not the vertebral body, as to the interface with the cortical bone, which is highest in the pedicle. This concept also applies for iliac screws.

While iliac screws are frequently used in daily routine, published complication rates as well as revision rates are still high (21.0-27.9%) (7, 8). Reasons for revision surgery include but are not limited to screw loosening (20%), implant breakage (12%), implant prominence (14-18.1%), and wound infection (22-25.4%) (8, 9). As always, revision surgery can be challenging. Therefore, primary optimal screw placement for best distal anchorage is crucial.

Biomechanic strength and therefore efficacy of lumbopelvic fixation (LPS) hinges upon the precise positioning of iliac screws. To ascertain, if published studies resulted in clinical improvement already, the primary objective of this study therefore was to systematically evaluate anatomic iliac screw placement. Furthermore, we analysed possible related soft tissue complications.

Patients and Methods

This study was approved by our local ethics committee (No.: 2218-2014.). We searched our database for skeletal mature patients who underwent primary lumbopelvic stabilization with the use of iliac screws and had digitally available postoperative pelvic CT imaging. Exclusion criteria were more than one iliac screw per side as well as prior lumbopelvic stabilization. No restrictions were made as to demographic criteria or, for example, length of construct. Postoperative CT imaging was analysed using the software Visage 7® (Visage Imaging GmbH, Berlin, Germany). Based on general anatomy as well as criteria published by Schildhauer *et. al*., different landmarks were used to describe iliac screw positioning (Table I) (5, 10).

All landmarks described in Table I are visualized in Figure 1.

Three-dimensional screw positioning was defined by the angle of the screw compared to the sagittal and transverse plane. Perfect orientation is displayed in Figure 1 and defined by PSIS, anterior inferior iliac spine (AIIS)

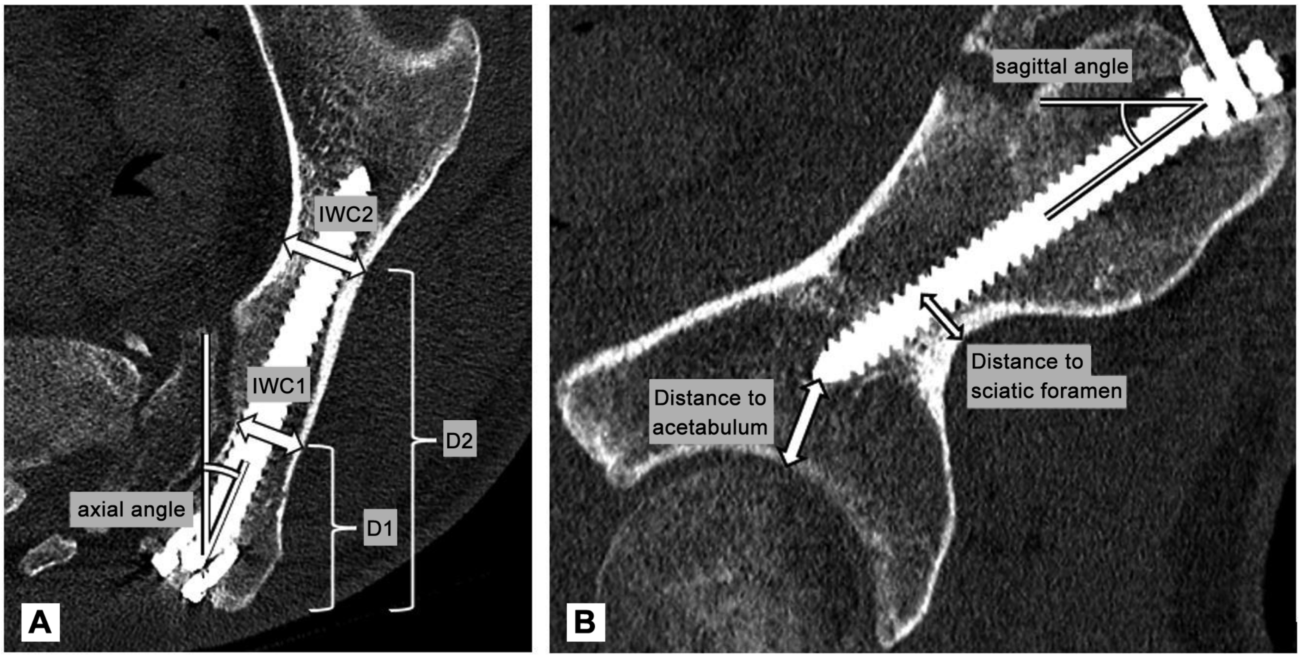

Figure 1. *Computed tomography (CT) imaging following iliac screw placement. The iliac screw is demonstrated in the axial plane (A) and sagittal plane (B). Anatomic landmarks described in Table I are highlighted. Besides described anatomic landmarks, it can also be seen that the screw head is beneath the most posterior prominence of the posterior superior iliac spine (PSIS), which is clinically important to reduce symptomatic implant prominence.*

as well as screw passing through the two inner widths to achieve an optimal implant-bone-interface. For measurements, transverse planes were tilted until sufficient evaluation of screw channels could be performed. Overall pelvic size was described using three further anatomic parameters: interspinous distance, intercristal distance and transversal distance (Figure 2).

Lengths and diameters of implanted iliac screws were taken from surgical reports. Moreover, these values were controlled by CT measurements. Each screw was evaluated as to its anatomic placement and relation to parameters introduced in Table I. Related clinical soft tissue complications were elaborated from patient charts. The complications are classified as intraoperative, clinical postoperative, and isolated radiologically, each with and without clinical relevance. The last classification was deliberately considered as complications although it does not have to be one. However, this may be assessed differently depending on the definition and author (11).

Statistical analysis was performed using SPSS version 22 (IBM, Armonk, NY, USA). Chi-square test as well as Pearson correlation and Spearmen's rank correlation were used. *p*-Values ≤0.05 were considered statistically significant. For the following part the letter P represents the Pearson correlation coefficient, whereas *p* represents significance.

Results

Postoperative CT scans were available for 27 patients. We included 24 (14 females, 10 males) into this study. Due to exclusion of one side in a patient (due to implantation of two iliac screws within one iliac wing), we did finally include 47 iliac screws into this study.

The mean age of patients at the time of surgery was 56.4 years (17.6-87.5 years), the mean body mass index (BMI) was 25.4 kg/m^2 (17.2-40.4 kg/m^2) with an average height of 1.71 m (1.53-1.90 m) and an average weight of

Table I. *Anatomic parameters to describe the iliac screw channel.*

Landmark	Description
Posterior superior iliac spine (PSIS)	Defined anatomically
Sciatic foramen	Defined anatomically
Distance: Sciatic foramen – screw entry point	Shortest distance between the most cranial part of the sciatic foramen and the center of the screw at the screw entry point in the ilium
Anterior inferior iliac spine (AIIS)	Defined anatomically
Distance to the acetabulum	Shortest distance between screw tip and acetabulum
C1	Posterior constriction of the ilium in the axial plane
C2	Anterior constriction of the ilium in the axial plane
IWC1	Inner width 1: smallest intercortical distance at C1
IWC2	Inner width 2: smallest intercortical distance at C2
D1	Distance: C1 – screw entry point
D2	Distance: C2 – screw entry point

Table II. *Screw dimensions and orientation with regards to pelvic anatomy.*

	N	Minimum	Maximum	M	SD
Diameter (mm)	45	6.0	9.0	7.9	0.7
Length (mm)	45	42.0	80.0	71.2	13.7
Angle axial (˚)	44	6.7	66.1	30.7	12.6
Angle sagittal (˚)	44	5.7	65.9	34.2	13.0
Distance PSIS (mm)	42	2.0	38.6	16.2	8.1
IWC_1 (mm)	43	7.3	17.7	12.6	2.5
D_1 (mm)	43	11.1	43.9	28.2	8.3
IWC_2 (mm)	39	7.4	19.6	13.6	3.6
D_2 (mm)	39	51.4	90.9	74.5	9.0
Distance acetabulum (mm)	34	20.9	70.7	44.6	12.0
Distance foramen (mm)	23	8.1	38.2	23.8	7.9

N: Number of screws; M: average value; SD: standard deviation; PSIS: posterior superior iliac spine; IWC1: Inner width 1; D1: distance constriction 1 – screw entry point; IWC2: Inner width 2; D2: distance constriction 2 – screw entry point; Distance acetabulum: distance from screw entry point to acetabulum; Distance foramen: distance from the screw entry point to the sciatic foramen.

74.4 kg (43.0-110.0 kg). Indications for surgery were traumatic fracture (30.4%), tumor (30.4%), insufficiency fracture (17.4%) and spondylodiscitis or spondylolisthesis (8.4% each). Sixteen out of 24 patients underwent open surgery, while eight were treated with minimally invasive procedures. Iliac screws measured 71.2±13.7 mm in length with a mean diameter of 7.9±0.7 mm. Lateral divergence, described by the axial angle, was 30.7±12.6˚, whereas caudal orientation, described by the sagittal angle, was 34.2±13.0˚. The mean distance from the entry point to the PSIS was 16.2 (±8.1) mm. D1 (distance 1: C1 – screw entry point) was 28.2 (±8.3) mm and IWC1 (inner width 1: smallest intercortical distance at C1) was 12.6 (±2.5) mm. D2 (distance 2: C2 – screw entry point) was 74.5 (±9.0) mm and IWC2 (inner width 2: smallest intercortical distance C2) was 13.5 (±3.6) mm. The mean distance to the acetabulum was 44.6 (±12.0) mm, and that to the sciatic foramen 23.8 (±7.9) mm. Screw dimensions and anatomic orientation are summarized in Table II.

The variant number of screws can be attributed, in some cases, to either poor CT quality or incomplete visualization the anatomic parameter and/or screws. A significant correlation was found between IWC1 and the distance from the screw entry point to the PSIS (P=0.46, $p<0.01$, n=40). The more cranial or caudal the screw entry point was chosen in relation to the PSIS, the wider the constriction C1 became. The distance D1 correlated significantly with the distance of the screw tip to the acetabulum (P=0.37, $p=0.03$, n=34), and with the distance to the sciatic foramen (P=0.56, $p<0.01$, n=23). Furthermore, we found a correlation between D2 and the distance to the acetabulum (P=0.42, $p=0.02$, n=32) and between the distance to the acetabulum and the distance to the sciatic foramen (P=0.58, $p<0.01$, n=23). The correlation of D1 and D2 with the distance of the screw tip till the acetabulum indicates that longer screws would have been possible in these cases. However, no statistically significant dependencies were found between the widths of the constrictions and the distances to the sciatic foramen or acetabulum.

Nevertheless, pelvic dimensions correlated significantly with each other and also with the length of implanted

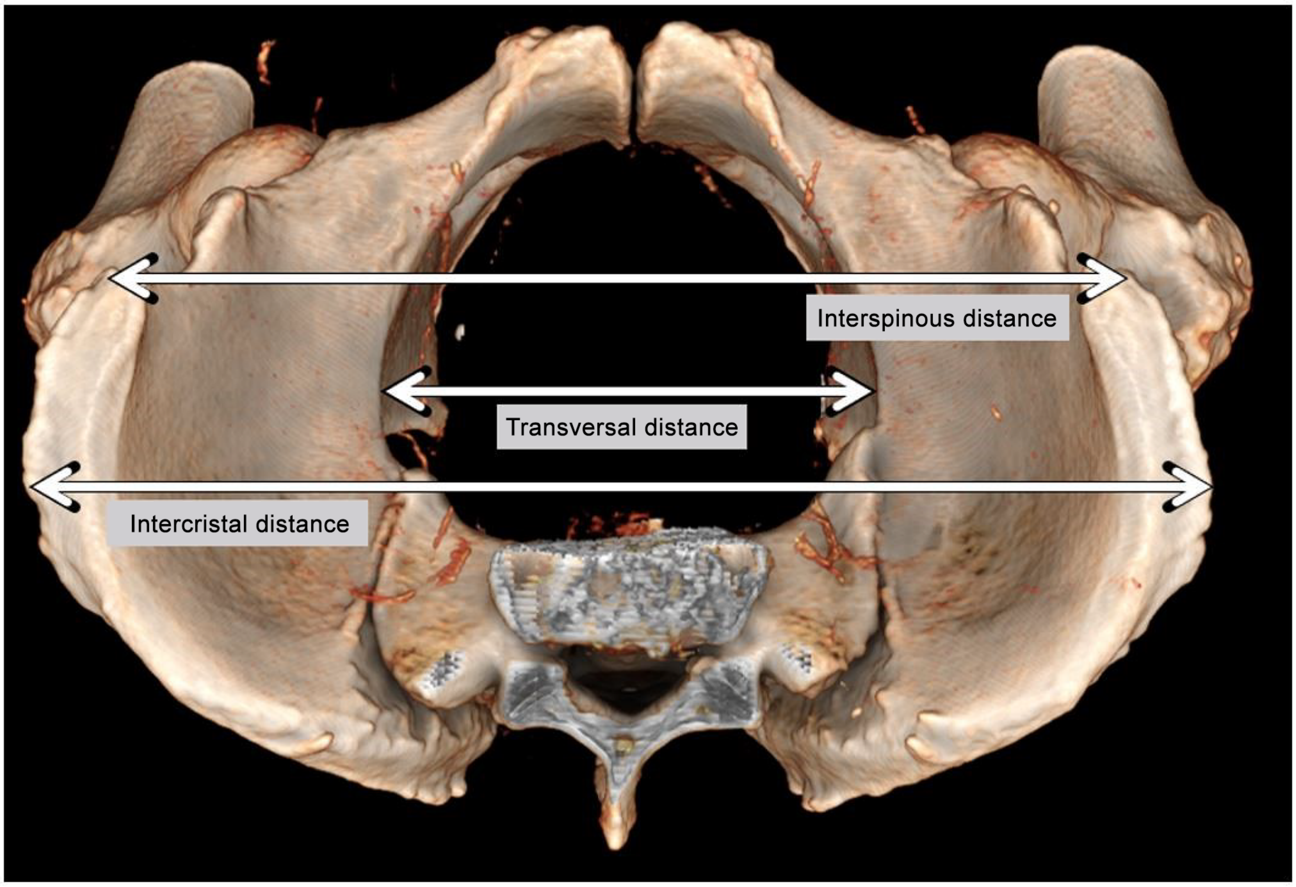

Figure 2. *Parameters to describe the overall pelvic size. The intercristal distance describes the widest length of the pelvis. It is defined as the length between the two iliac crests. The interspinous distance represents the length between the anterior superior iliac spines. The transversal distance defines the outlet of the pelvis.*

screws (Table III). Evaluation of our data demonstrated that selection of the screw length was significantly dependent on the interspinous distance (P=0.49, $p<0.01$, n=45), on the intercristal distance (P=0.38, $p=0.01$, n=45) and from the transverse diameter (P=0.31, $p=0.04$, n=45), indicating, that in general, surgeons did tend to use longer screws in bigger pelvises. However, no correlation of general pelvic dimensions and screw diameter was found.

Table IV summarizes the intraoperative, clinical postoperative, and purely radiological complications that occurred. As intraoperative complications nine implanted screws (20%) were malpositioned with partial extraosseous placement. Clinical postoperative complications included pain located above the iliac screws during follow-up. Wound infections occurred in four patients (8.9%), and three patients (6.7%) experienced prolonged wound healing. Isolated radiological complications were described in five patients (11.1%) which demonstrated screw loosening during follow-up controls without any evidence of clinical issues and significant correlation. In 33.3% no complications were detected.

A classification of the patient groups according to the occurrence of wound complications (dehiscence or wound infection) with determination of the average distance of the entry point to the PSIS did not result in any statistically significant correlation (P=–0.24, $p=0.81$).

Table III. *Correlation between pelvic dimensions and screw dimensions.*

		Interspinous distance	Intercristal distance	Transversal distance	Screw diameter	Screw length
Interspinous distance	P	1	0.85	0.71	0.19	0.49
	p		**0.00**	**0.00**	0.22	**0.00**
	N	45	45	45	45	45
Intercristal distance	P	0.85	1	0.64	0.16	0.38
	p	**0.00**		**0.00**	0.31	**0.01**
	N	45	45	45	45	45
Transversal distance	P	0.71	0.64	1	–0.14	0.31
	p	**0.00**	**0.00**		0.36	**0.04**
	N	45	45	45	45	45
Screw diameter	P	0.19	0.16	–0.14	1	0.62
	p	0.22	0.31	0.36		**0.00**
	N	45	45	45	45	45
Screw length	P	0.49	0.38	0.31	0.62	1
	p	**0.00**	**0.01**	**0.04**	**0.00**	
	N	45	45	45	45	0

P: Correlation coefficient; p: significance; N: number of screws. Bold values indicate statistical significance.

Revision surgery was required in six patients (25%), in four (16.7%) of them due to a wound infection, with one patient, however, already being diagnosed preoperatively with a prevertebral abscess. One of them underwent revision because of healing problems due to malalignment, and another one due to pain above prominent screws. One patient had cement leakage into the sciatic foramen following screw augmentation. Nevertheless, this patient had no associated symptoms during follow-up. In summary, revision surgery primarily occurred due to clinical postoperative complications, with radiological complications accounting for a minority of cases.

Table IV. *Complications being associated with iliac screws.*

Complication	N	Proportion (in %)
Intraoperative		
- Extracortical malposition	9	20
Clinical postoperative		
- Painful prominence	9	20
- Wound infection	4	8.9
- Wound healing disorder	3	6.7
Isolated radiological		
- Screw loosening	5	11.1

Discussion

Our study demonstrates radiological results following iliac screw placement, defined by anatomic landmarks. The overall complication rate was high but within the values found by other authors. Different studies published complication rates for iliac screws being as high as 12-26% (8, 9).

Doubtless, biomechanical stability and distal anchorage much depend on optimal iliac screw placement as well as correct implant dimensions to achieve an optimal implant-bone-interface (2, 5). The part below discusses some attempts. The lumbosacral pivot, identified between lumbar vertebral body 5 (L5) and the sacrum, highlights increased stability when the screw tip is positioned as anterior as possible (12). In this study, iliac screws measured 71 mm on average, with a mean distance from the screw tip to the acetabulum of about 45 mm, indicating the potential to increase screw length by 20-30 mm without risking acetabular perforation. It also revealed that achieving constriction C2, located approximately 75 mm from the entry point, with an average screw length of 71 mm was not feasible. Therefore, based on our data (length 71.2±13.7 mm, diameter of 7.9±0.7 mm), the surgeons who performed the surgical cases being included into this study did often tend to use too short screws to at least reach both iliac constrictions, which might be important to increase the implant-bone-interface. Additional screw lengths of at least 100 mm would be necessary to safely bridge C2 (5). Schildhauer *et al*. and Park *et al.* reported similar findings, recommending minimum screw lengths of 120 mm for males and 90 mm for females to at least pass through constriction C2, with Park *et al.* specifying a maximum acceptable range for males (113-124 mm) and females (104-113 mm) (5, 13). Therefore, the implantation of larger screws would be possible. While our study observed an average iliac screw diameter of 7.9 mm, considering the anatomical width of C1 (12.6 mm) and C2 (13.5 mm), screw diameters were often chosen too small to achieve an optimal cortical contact of iliac screws. Schildhauer *et al.* advocated a maximum diameter of 8 mm, whereas Park *et al.* measured diameters exceeding 9 mm in some cases, similar findings as our study (5, 13).

In general, as anatomical parameters of the bony pelvis increase, selecting bigger implants becomes important for optimal biomechanical stability. This highlights the need for individual surgical CT-based planning. Our finding that C2 in our study often was not perfectly within the screw vector due to the sagittal angle of implantation also underscore the need for individual surgical CT-based planning (2, 5, 14). We found no significant relationship between passing the constriction and the occurrence of extracortical position or screw loosening. This suggests that the bottlenecks may not necessarily need to be part of the screw channel to achieve the most stable construction with a low non-union rate (5). However, significant deviations from the bottlenecks could result in a higher penetration rate in those locations. Surgeons may opt for smaller screw diameters and lengths due to concerns about penetration risks, leading to potential extracortical malposition. Some biomechanical studies suggest that longer iliac screws result in significantly higher stability regarding isolated *pull-out force*, with no significant differences in torsional and compressive stiffness for various screw lengths (15). Physiological forces demonstrate no significant differences in the pull-out phenomenon between different screw lengths as well, suggesting that screw length is not of primary importance in relation to everyday stress (more below) (16). Under maximum load, Akesen *et al.* and Wang *et al.* found reduced loosening rates for thicker screws, while longer screws showed the opposite phenomenon (14, 17). In summary, iliac screw diameters appear to be more crucial than length as above mentioned. According to studies by Zheng *et al.* and Akesen *et al.,* a reduced screw length may compensate for an increased diameter while maintaining sufficient stability (14, 15).

Based on these findings, the use of short and thick screws is recommended to minimize this risk of penetration while ensuring sufficient biomechanical stability. In cases of questionable stability with short screws, an alternative could be cementing the screws, with caution due to potential difficulties in revision (14). The challenge of explanting a mal-positioned screw may contribute to this choice. Alternatively, the use of S2 alar-iliac screws could be an option (1).

Our results for screw angulation differ from published data, with tendency to higher axial angulation (30.7° *vs*. 21-22°) but similar sagittal angulation (34.0° *vs*. 27-39°) (18). While different authors recommend different angulations, Katsuura *et al.* recommend angles of 25° (sagittal) and 22° (axial) to minimize complications, as extracortical positioning, to achieve maximal length. The variation of study results highlights again the need for individual preoperative CT-based planning (19). This is especially relevant, as all cited studies represent Caucasian populations. Different populations, however, might even have more aberrating normal ranges. The more caudal the sagittal orientation of iliac screws is (our findings recommend a caudal orientation between 30-35°), the more constrictions C1 and C2 eliminate, allowing for a larger screw diameter, however, possibly requiring shorter screws to avoid cortical perforation. A more cranial orientation of the screw channel may decrease screw stability and intercortical contact by passing through the region above the sciatic foramen, which has the highest substance content, if the screw diameter is too low (20). As described above, while there is a tendency to change biomechanical testing from isolated pull-out force to more physiologic craniocaudal repetitive cyclic load, this might affect the approach of understanding lumbopelvic stability (21). Consequently, screws demonstrating stability under pull-out force and a low intraosseous loosening rate may not necessarily exhibit the same stability under craniocaudal cyclic loads (16). This attempt to explain the relevance of interaction between screw size and placement relative to the individual anatomy, however, is not biomechanically proven. Therefore, preoperative measurement of the selected screw channel using a CT scan is crucial for optimizing screw placement.

Park *et al.* investigated the impact of the entry point relative to the PSIS on iliac screw parameters. Optimal entry was within 10 mm superior to 10 mm inferior to the PSIS, with maximum length observed in the medial quarter (22). Other studies recommend screw entry points 10 mm superior or 10 mm medial and 10 mm caudal to the PSIS for biomechanical stability and construction stiffness (22, 23). Medializing the entry point is advised to facilitate deep insertion and prevent screw prominence (2, 23, 24). Despite these considerations, our study found no correlation between the distance of the entry point to the PSIS and length to anatomical landmarks or soft tissue complications.

Literature indicates that the majority of the complications were described as clinical postoperative ones with healing disorders 31.7% or screw related pain/prominence 14.0-18.1% with a need for revision in 21.0-27.9% of cases (7, 8). This might be prevented by the use of S2AI screws, however, these cannot be used in cases where the sacrum is weakened, *i.e.,* due to a tumor or a fracture (1). Regarding intraoperative complications, we found extracortical malpositioning in 15.6% of cases, which is in the published range of 2-59% (5, 25, 26). This might be prevented by the use of modern technologies like three-dimensional fluoroscopy or even navigation (10, 27). Regarding radiological complications, our study observed screw loosening in 11.1% of cases, a lower frequency compared to Gao *et al.* who published a rate of 20% (9). The clinical implications of radiographic evidence of implant loosening are unclear, as studies suggest that 70% of loosened iliac screws may lack clinical relevance (28). Some authors interpret screw loosening as a positive sign, indicating force transmission and protection of the sacrum (24, 29). However, this would only be favourable in cases where the sacrum can heal, like after fracture. In cases with intended lumbopelvic bony fusion, screw loosening could also be an indicator for non-union (30). Consequently, therefore, the assessment of implant loosening should consider the clinical context and patient symptoms.

Generally iliac screws are riskier for complications compared to S2AI screws because of their revision rate (revision rate: S2-alar-iliac screw 14.2%, iliac screw 27.9%) (8). Invasiveness is also considered high when implanted using an open approach (30). This aspect may limit the utilization of minimally invasive techniques.

Conclusion

Our data suggest that optimal iliac screw size relative to the individual anatomy in general is not achieved. Perfect anatomic placement can be challenging, which highlights the need for individual preoperative CT-based surgical planning to achieve a strong caudal anchorage in lumbopelvic fixations. In general, the diameter seems to be more important than the screw length.

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Authors' Contributions

Fritzsche Carina and Mahjoub Samy contributed equally to all aspects of this work.

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Conflicts of Interest

There are no conflicts of interest to declare in relation to this study.

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