Clinical Studies

Pelvic parameters directly influence ideal S2 alar-iliac (S2AI) screw trajectory

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A R T I C L E   I N F O

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A B S T R A C T

Background: The utilization of the S2 Alar-Iliac (S2AI) screw provides an optimal method of spinopelvic fixation. The free-hand placement of these screws obviates the use of intra-operative fluoroscopy and relies heavily on sacropelvic anatomy; variations of this anatomy could alter the ideal screw trajectory. The S2AI corridor is near several neurovascular structures, thus an accurate trajectory is critical. The reported angles of trajectory vary within the literature and a paucity of data exists on how patient morphometry influences ideal screw trajectory. We sought to examine the relationship between ideal screw trajectory and pelvic parameters.

Methods: The records of 99 consecutive patients with degenerative thoracolumbar pathology were reviewed and pelvic parameters including sacral slope, pelvic tilt, and pelvic incidence were measured with preoperative standing radiographs. Using 3-dimensional computed tomography (CT) reconstructions, an ideal S2AI trajectory was defined and anteroposterior (horizontal) and cephalocalvarial (sagittal) angles were recorded.

Results: Pelvic tilt was found to have a moderate inverse correlation with cephalocalvarial screw trajectory (r = -0.467, p-value = 0.006). Pelvic incidence and sacral slope had weaker correlations with cephalocalvarial screw angle. In subgroup analysis, patients with high pelvic tilt (>20°) had a significantly lower cephalocalvarial screw trajectory (24.9 ± 3.7° versus 29.8 ± 2.8°, p-values = <0.001) compared to those with a normal pelvic tilt (≤20°).

Conclusions: This study found an inverse relationship between pelvic tilt and cephalocalvarial S2AI screw trajectory. Therefore, the sagittal angle of insertion becomes increasingly more perpendicular to the floor (less caudally orientated) as pelvic tilt increases in reference to a patient positioned prone on an operating table parallel to the floor. This may bolster safety and efficacy when utilizing the free-hand technique for placement of the S2AI screw as it allows the surgeon to plan a more ideal trajectory by accounting for pelvic parameters.

Introduction

Spinopelvic instrumentation is an important tool in the armamentarium of the spine surgeon; this modality aids in the treatment of scoliosis, in fusions of osteoporotic degenerative disease, and in the reduction of high-grade spondylolisthesis and spinopelvic dissociation [1–4]. The addition of pelvic fixation may increase the overall biomechanical integrity and decrease failure under load, especially with long constructs [5,6].

The S2 Alar-Iliac (S2AI) screw is a recent advancement in spinopelvic fixation [7]. First described by Spine and Kebaish in the setting of pediatric [8] and adult deformity [9], this modality offers several advantages including tricortical purchase [10], ease of rod placement [11], limited sacropelvic dissection [11], and decreased screw prominence [10–12]. Decreased rates of surgical site infection, reoperation, and wound dehiscence have been reported when compared to spinopelvic fixation utilizing the iliac screw [10,12]. Traditionally, the screw is placed under fluoroscopy [11], however placement under stereotactic navigation [13] or with robotic guidance [14] has also been described. More recently, the free-hand technique, which precludes the need for intraoperative fluoroscopy by relying on the surrounding sacropelvic anatomy, was introduced [15,16]. Shillingford, Laratta, Lenke, and col-
leagues demonstrated the free-hand technique as safe and reliable for placing S2AI screws in adults with spinal deformity [15,17]. The S2AI starting point has been well-described as midway between the S1 and S2 foramina and at their lateral border [11]. However, screw angulation and trajectory rely on patient-specific anatomic landmarks [15,18]. It is essential for the anteroposterior trajectory to avoid the pelvis proper anteromedially, and for the cephalocaudal trajectory to avoid the sciatic notch inferiorly; Fig. 1 demonstrates the insertion point and screw trajectory. (Fig. 1) Although the anteroposterior trajectory is typically obtained by dropping the hand until the gearshift rests on the sacral spinous processes and the cephalocaudal trajectory is obtained by aiming perpendicular to the sacral laminar slope [18] or just distal to the PSIS (posterior superior iliac spine) [15], these angulations may vary significantly from patient to patient.

Patients with spinal deformity, a population in which the S2AI screw is frequently utilized, have significant spinopelvic compensatory changes which may alter the surgeon’s planned S2AI trajectory [19–25]. Therefore, the consideration of pelvic parameters may aid in the safe free-hand placement of these screws. To date, there has been no published literature on what role pelvic parameters play in determining the accuracy of S2AI screw placement. This study sought to evaluate the relationship of pelvic parameters and ideal S2AI screw trajectory.

Methods

In this single center, retrospective series spanning 2015 to 2016, the medical records and preoperative computed tomography (CT) scans of 99 consecutive patients with degenerative thoracolumbar pathology were reviewed by two independent investigators (J.L.L. and J.N.S.). The inclusion criteria were as follows: patients > 18 years of age, degenerative thoracolumbar pathology, and the presence of both lumbar CT scan and upright radiographs. Thoracolumbar pathology included spondylolisthesis, degenerative scoliosis, and lumbar spondylosis/stenosis. Patients with neoplastic processes of primary or metastatic etiology were excluded, as were patients with prior thoracolumbar surgery. The study protocol was reviewed and approved by our University’s Institutional Review Board (IRB). Preoperative standing radiographs were assessed to measure pelvic parameters including sacral slope, pelvic tilt, and pelvic incidence as defined in previous studies [26,27]. A 2-dimensional rendering of these pelvic parameters can be seen in Fig. 2. (Fig. 2) Three-dimensional interactive viewing and manipulation of the CT images with VitreaCore software (VITAL version 6.7.6, A Toshiba Medical Systems Group Company) allowed for creation of an “ideal” S2AI trajectory.

An ideal S2AI trajectory was defined as the starting point midway between the S1 and S2 foramina with a screw axis orientated cephalocaudally toward the anterior-inferior iliac spine (AIIS) within the sagittal plane. In the axial plane, the trajectory started at the lateral aspect of the S1 and S2 foramina and was directed through the narrowest portion of the ilium. Anteroposterior (horizontal) and cephalocaudal (sagittal) angles were recorded.

Statistical analysis

SPSS Statistics v24.0 (IBM Corp, Armonk NY) was utilized to analyze the data. Pearson correlation coefficient (r) and independent Student’s
Table 1
Patient characteristics and average ideal S2AI screw insertion angles.

| Patient Characteristics | | |
|-------------------------|--|--|
| Total Number of Patients | 99 | |
| Mean Age, years | 62.4 ± 12.5 | |
| Female Patients (%) | 42 (42.4) | |
| Average Ideal Screw Insertion Angles | | |
| Sagittal Angle | 27.3 ± 4.1° | |
| Horizontal Angle | 35.9 ± 3.9° | |

Table 2
Correlation of sagittal screw angle to pelvic parameters.

| Sagittal Screw Angle Correlation to Pelvic Parameters | | |
| Pelvic Parameter | Pearson Correlation (r) | p-Value |
|------------------|-------------------------|---------|
| Pelvic Tilt | -0.467 | **0.006** |
| Sacral Slope | 0.212 | 0.236 |
| Pelvic Incidence | -0.140 | 0.437 |

T-test were used to demonstrate correlation and test for significance respectively in the values of pelvic tilt, sacral slope, and pelvic incidence versus cephalocaudal screw trajectory. Further subgroup analysis was attained where groups of high (>20°) and low (≤20°) pelvic tilt were compared to cephalocaudal and anteroposterior angle utilizing an independent Student’s T-test. Findings were considered significant when a p-value was found to be <0.05.

Results

Demographical data

A total of 99 patients were included in this study, of this number, 42 (42.4%) were female. The mean age was 62.4 ± 12.5 years.

Imaging data

The average cephalocaudal angle measured 27.3 ± 4.1° in the sagittal plane. The average anteroposterior angle measured in the axial plane in respect to the PSIS was 35.9 ± 3.9° (Table 1).

Statistical results

Pelvic tilt was found to have a statically significant, moderate inverse correlation with cephalocaudal screw trajectory (r=-0.467, p-value=0.006). Sacral slope demonstrated a weak direct correlation with cephalocaudal screw angle (r=0.212, p-value=0.236), while pelvic incidence was weakly correlated to cephalocaudal screw angle inversely (r=-0.140, p-value=0.437). (Table 2) Graphical representation of pelvic tilt, sacral slope, and pelvic incidence versus cephalocaudal screw angle in a linear regression model can be seen in Figs. 3–5, respectively.

Subgroup analysis

Patients grouped into a category of high pelvic tilt (>20°) were shown to have a statistically significant lower cephalocaudal angulation of screw trajectory when compared to patients with a pelvic tilt of ≤20° (24.9 ± 3.7° versus 29.8 ± 2.8° respectively, p-value <0.001). (Table 3) A radiographic depiction of the ideal projected S2AI trajectory in patients with pelvic tilts of 30° and 10° can be seen in Fig. 6.

Discussion

The free-hand placement of the S2AI screw in the setting of adult spinal deformity was first described by Shillingford, Laratta, Lenke, and colleagues [15]. Patients with sagittal deformity demonstrate a cascade of compensatory mechanisms to maintain an upright posture, including increased pelvic tilt (pelvic retroversion) and decreased sacral slope [19–25]. Variations of sacropelvic anatomy could affect the ideal screw trajectory and an accurate trajectory is critical as the S2AI corridor traverses near several vital neurovascular structures [28, 29]. Although the placement of these screws has been demonstrated to be safe and effective without fluoroscopic guidance and equally as safe as robotic assisted placement [15, 17], the relationship of pelvic parameters and screw trajectory had yet to be studied.

The surrounding sacropelvic anatomy predicates the placement and path of the S2AI screw when using the free-hand technique [15, 16, 18]. The starting point is described as the midpoint between the S1 and S2 foramina and 3 mm lateral to the sacral crest while directing the screw to a point just superior to the posterior distal edge of the PSIS and perpendicular to the lateral sacral crest [15]. The resultant angles of trajectory have been reported in several papers, ranging from 27.5° to 48.8° and 30.8° to 67.3° in the sagittal and horizontal planes in one literature review including seven studies [30]. Park et al. noted an average anteroposterior angle of 32.0 ± 1.8° and a cephalocaudal angle of 17.3 ± 5.4° amongst 4 cadaveric specimens without deformity [16]. Shillingford and colleagues reported an average cephalocaudal angle of 24.2° ± 10° and an anteroposterior angle of 39.3 ± 8.2° [15]. Our study found a cephalocaudal angle of 27.3 ± 4.1° and an anteroposterior angle of 35.9 ± 3.9°. While the literature reports a relatively large range regarding the angles of trajectory, there is a paucity of literature regarding the impact of patient morphometry upon the ideal S2AI trajectory.

Other variations of ideal S2AI screw trajectory have been reported in the literature. Work by Zhu et al. within the Chinese population demonstrated a significantly greater cephalocaudal trajectory within females, concluding the trajectory should be 5° more caudal than the recommended 30° in males of Chinese descent [31]. Li et al. concurred in their own study, reporting an additional 5° of caudal angulation within the sagittal plane was necessary in females versus males undergoing S2AI fixation [32]. With the free-hand technique in an adult deformity population, a greater anteroposterior angle was noted amongst screws with posterior cortical breach (44.4 ± 6.8°) compared to those without cortical breach (38.9 ± 8.2°) [15]. Our study demonstrated a significant inverse correlation where with increasing pelvic tilt, the ideal S2AI trajectory became less caudally angled. This relationship may be of importance within the adult spinal deformity population. These patients have higher pelvic tilts than asymptomatic volunteers [24, 25] and are a group in which the S2AI screw is used frequently. Our findings suggest a less caudally angled trajectory is ideal amongst this group of patients.

An ideal trajectory of the S2AI screw is vital as inaccurate placement may cause cortical breach resulting in risk of iatrogenic injury. Anatomical studies have elucidated the proximate relationship of the screw corridor and several soft tissue structures within the pelvis. These vital structures include the abdominal and pelvic viscera anteromedially, the internal iliac vessels, obturator nerve, lumbosacral trunk, and sacral plexus medially [28, 29]. Immediately inferior of the screw corridor lies the sciatic notch which contains a plethora of structures including the superior gluteal neurovasculature just superior to the piriformis muscle, sciatic nerve, internal pudendal vessels, and pudendal nerve [33]. A trajectory too caudal risks violating the sciatic notch potentially resulting in devastating complications; this underscores the importance of our data demonstrating that a less caudal S2AI screw trajectory is ideal in patients with a high pelvic tilt. Furthermore, the area that traverses immediately superior to the sciatic notch has purchase through the dense cortical bone of this area and yields an increased pullout strength [33]; therefore, an angle not caudal enough in patients with a lower pelvic tilt would miss this area of denser bone. Thus, the consideration of pelvic parameters may augment both the safety and efficacy of free-hand S2AI screw placement.

In consideration of these findings, several limitations exist within this study. First and foremost, the retrospective nature promotes only the
Table 3
Subgroup analysis of patients with low and high pelvic tilt.

|                           | Low Pelvic Tilt (≤20°) | High Pelvic Tilt (>20°) | p-Value |
|---------------------------|------------------------|-------------------------|---------|
| Number of patients (%)    | 48 (48.5)              | 51 (51.5)               |         |
| Sagittal Angle            | 29.8 ± 2.8°            | 24.9 ± 3.7°             | <0.001  |
| Horizontal Angle          | 36.2 ± 4.9°            | 35.7 ± 2.8°             | 0.746   |

Significant p-values (p<0.05) are bolded.
hypothesis that pelvic parameters influence S2AI screw trajectory. Also, the limited sample size of 99 patients may decrease the generalizability of the results. A prospective design comparing S2AI screw trajectory amongst cohorts stratified by pelvic parameters would further support the findings of our study.

Conclusions

This study found a statistically significant inverse correlation between pelvic tilt and the ideal cephalocaudal trajectory of the S2AI screw. The free-hand technique allows for the surgeon to safely place S2AI screws without fluoroscopy, but the trajectory relies heavily on the surrounding sacropelvic anatomy. Our study proposes that as the pelvic tilt increases (as measured on preoperative standing radiographs), the angle of S2AI insertion becomes increasingly more perpendicular to the floor (less caudal) and as pelvic tilt decreases, the angle becomes increasingly more parallel to the floor (more caudal) in reference to the patient lying on a table prone and parallel to the floor. This translates to the surgeon holding the gearshift probe more upright in patients with high pelvic tilt and dropping his or her hand toward the head of the patient to obtain a more caudal angle in patients with low pelvic tilt. Should this angle be too caudal, the sciatic notch may inadvertently be violated potentially resulting in iatrogenic injury; an angle too cephalad may decrease screw pull-out strength by missing the dense cortical bone just superior of the sciatic notch. Therefore, the consideration of pelvic parameters may bolster the safety and efficacy of S2AI screw placement using the free-hand technique.

Disclosures

This study received no means of outside funding. There are no known conflicts of interest amongst the authors that pertain to the contents of this manuscript. A full disclosure statement of each author is accompanied in this submission.
Declaration of Competing Interest

None.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jrs.2020.100014.

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