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IDEAS AND TECHNICAL INNOVATIONS

S2 alar iliac screw placement under robotic guidance for adult spinal deformity patients: technical note

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Abstract

Purpose S2 alar-iliac (S2AI) screws are generally placed using an open approach, but have recently been shown to be implantable using a minimally invasive approach. Nevertheless, optimal screw positioning, even when supported by fluoroscopic guidance, is challenging in the complex anatomy of the sacral-pelvic area. This work presents our novel technique of S2AI sacropelvic fixation procedures performed with robotic guidance.

Methods This was a single-center, retrospective, mini case-series of adult spinal deformity patients in need of sacropelvic fixation as part of a longer thoraco-lumbar fusion. The surgeon drilled a pilot hole through a robotic guide and then inserted a K-wire. A Jamshidi needle was placed over the K-wire and used to advance the pilot hole anterolaterally.

Results Medical charts of four 60–70 year-old patients, who underwent robotic-guided insertion of S2AI screws in a minimally invasive approach were reviewed. Follow-up ranged between 10 and 13 months. Post-operative CTs and X-rays showed all eight trajectories were fully within the bone and accurately placed. Average surgery time per patient was 13 min with 5.3 s of fluoroscopy per screw. No intra- or post-operative complications occurred.

Conclusions Robotic-guidance with a Jamshidi needle technique was a safe and effective means for implanting S2AI screws in a minimally invasive approach.

Keywords S2 alar-iliac screw · Robotic-guidance · Adult spinal deformity · Minimally invasive approach

Introduction

Sacropelvic integrity is essential in maintaining mobility and weight-bearing functions and typically requires correction in cases of lumbosacral instability, deformity, stenosis, pain or pseudarthrosis. The region poses significant technical challenges arising from complex anatomy and biomechanical forces impacting the lumbosacral junction [1–3]. Long fusions extending into the sacrum have been associated with poor outcomes, relatively high implant failure rates and a higher frequency of major complications [4–6], ascribed to inadequate bone quality and purchase, inappropriate screw implantation, and excessive loading resulting from long fusion above the sacrum [5–7].

Numerous augmentation options have been proposed to maximize the rigidity of internal fixation at the sacrum and to enhance biomechanical stabilization prospects [8]. The Galveston method, which involves insertion of a long rod through the posterior superior iliac spine (PSIS) between the tables of the ilium, has evolved to become the gold standard for spinal fixation requiring fusion to the sacrum [9, 10]. The technique secures sustained structural curve correction, restores lumbar lordosis and improves coronal and sagittal balance [6, 11]. However, it has been correlated with a high pseudarthrosis rate, a high incidence of proximal fixation pullout and has been shown to be less reliable in adults when compared to pediatric patients [2, 3, 12]. Moreover, rod loosening, presenting as marked radiolucency [13], and complex three-dimensional rod contouring have led many surgeons to abandon the

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technique in favor of alternative methods using sacral and iliosacral screws.

Iliac screw instrumentation involves modular screw attachment to the main spinal construct, introducing additional fixation points into the sacrum and lower lumbar vertebrae, which enhances rigidity of the implant and of the sacropelvic unit. In addition, implanted iliac screws dock more stably within the cancellous bone, as manifested by improved pull-out strength [14], and can be directed toward the dense cancellous region just above the sciatic notch [11]. However, while this technique is designed to connect directly to the main spinal construct, due to surgical technique and anatomical considerations, it might require use of offset connectors to achieve this. In such eventualities, the technique involves more soft tissue disruption and dissection. Furthermore, due to the anatomy, in some cases the screw heads are prominent and might lead to pain and even necessitate removal [3, 4, 6]. The S2 alar-iliac (S2AI) approach is a modification of the traditional iliac fixation technique, in that it exploits a unique S2-alar iliac trajectory to achieve purchase in the ilium and sacrum at a minimal offset from the spinal axis. Purchase of these two additional cortices improves biomechanical pullout strength, which is of particular clinical relevance in cases of poor bone quality. In parallel, the more anterior starting point when compared to traditional iliac fixation methods, the technique minimizes implant prominence and complication rates [15]. Moreover, the approach induces less tissue morbidity, due to elimination of the need for large incisions and exposure of the paraspinal muscles and fascia dissection in the sacrum. To date, S2AI surgeries are generally performed using an open approach, but has recently been shown to be feasible and safe using a minimally invasive approach [16, 17]. Nevertheless, optimal screw positioning, even when supported by fluoroscopic guidance, is challenging in the complex anatomy of the sacral-pelvic area and sacroiliac joint [15, 16, 18]. This work presents a retrospective analysis of four S2AI sacropelvic fixation procedures performed with robotic guidance to correct adult spinal deformities.

Methods

Study design and patients

This was a single-center, retrospective, mini case-series of adult spinal deformity patients in need of sacropelvic fixation as part of a longer thoraco-lumbar fusion.

Procedure

All surgeries were performed using the Renaissance surgical robot (Mazor Robotics, Caesarea, Israel) and its planning software, as previously described [19]. In short, a preoperative computed tomographic (CT) scan which included the entire pelvis was used to plan optimal screw sizes and trajectories aimed to reach the superior region of the lateral sacral projection as previously defined by Chang and colleagues [15] (Fig. 1). The starting point of the S2AI screw is located at the midpoint between the S1 and S2 foramen and 2 mm medial to the lateral sacral crest. In the operating room, the preoperative CT scan was loaded onto the robotic workstation and a mounting platform was connected directly to the patient's spine. A fiducial array was connected to the platform and two fluoroscopic images were acquired. The proprietary software performed an automatic registration process of the acquired images with the preoperative CT. Then the robot was placed on the bone-mounted platform, and dispatched to the predetermined position. Once above the predefined trajectory, it was fitted with the appropriate attachment arm, through which a drill sleeve was inserted and distally docked on the bone. The surgeon drilled a pilot hole, approximately 30 mm deep, through this guide and then inserted a K-wire (Fig. 2a). A Jamshidi needle (CareFusion, San Diego, CA) was placed over the K-wire and used to advance the pilot hole anterolaterally (Fig. 2b, c). A powered 5.5 mm cannulated tap was used followed by a 6.5 mm tap. Finally, an 8.5 mm screw was inserted. Fluoroscopy was used to confirm that the screw was fully within bone, in the desired trajectory.

Outcome parameters

Clinical records, postoperative radiographs and CT scans were analyzed to determine screw placement accuracy, screw position in relation to the sciatic notch and complication rates. Patient reported outcomes of quality of life were assessed using the Scoliosis Research Society-22 Questionnaire (SRS-22) before and after surgery.

Results

Four patients (3 females), age 66.5 (range 60–70) underwent robot-guided S2AI sacropelvic fixation to correct degenerative deformities by spinal fusions ranging from 4 to 15 levels (Table 1), involving a total of eight S2AI screws of which six were 80 mm in length and in one patient both screws were 90 mm. The net mean time of use of the robot was 13 min for screw placement utilizing 5.3 s of fluoro per screw on average. The follow-up period ranged between 10 and 13 months. The average pre-operative SRS-22 score was 1.8, while the postoperative SRS-22 increased to 3.6 ($p = 0.003$).

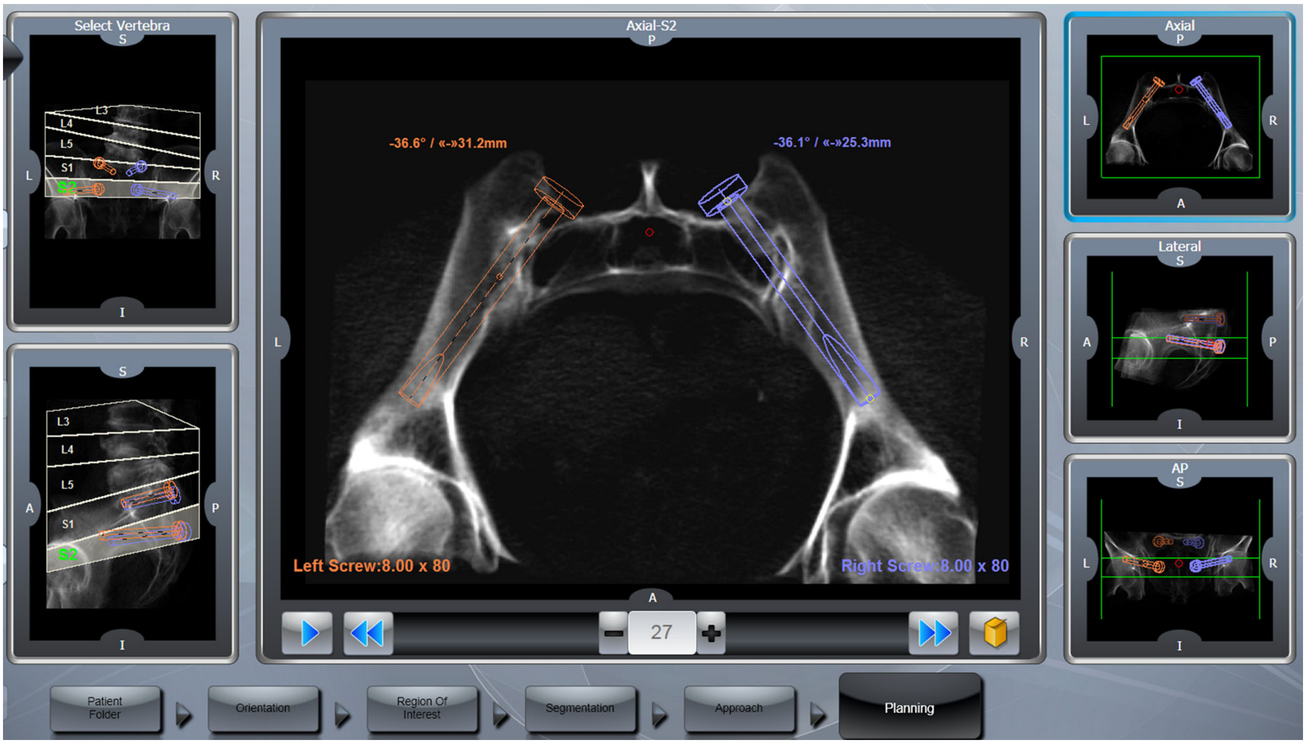

Fig. 1 Preoperative planning screen of the renaissance system

All four patients were imaged post-operatively with X-ray and CT scans, which confirmed that all screws were positioned accurately, just above the sciatic notch, with no proximal breaches of the anterior sacrum, and no protrusions from the ilium. No violations of the cortical wall, sciatic notch, acetabulum or pelvis were observed and no peri- or post-operative complications were reported. No revision or removal procedures were required.

Discussion

The S2AI approach affords multiple advantages in the anatomically and biomechanically complex sacropelvic region. The technique has been shown to better resist flexion cantilever forces at the lumbosacral junction, minimize implant prominence, obviate or significantly reduce the need for cross connectors, provide additional purchase by traversing the sacrum, reduce the high (60%) sacroiliac articular cartilage violation rate, with still unknown long-term consequences, and reduce dissection requirements in both adults and children [15]. Yet the process of envisioning the screw trajectory in the complex three-dimensional anatomy and then execution of this trajectory can be challenging. Integration of robotic guidance, which utilizes three-dimensional preoperative planning and mechanical guidance during the surgery, appeared as an appropriate mitigation of these challenges. There are many reports on the accuracy of pedicle screw placement with robotic-guidance [19–22] and has generally shown to improve placement accuracy over freehand techniques in comparative studies [23–26].

In the first report of robotic-guided S2AI procedures, Bederman et al. [27]. achieved accurate screw trajectories in all 31 placements, of which ten protruded anterolaterally by ≥4 mm, but posed no apparent risk and did not require removal or revision. Protruding screws correlated with their length, where only screws longer than 75 mm extended beyond the cortical boundaries. The reported surgical planning stage relied on CT images of the lumbosacral spine, with a limited view of the pelvis, as well as on software simulation limitations of virtual screws up to 60 mm long. Taken together, the platform provided limited viewing and trajectory planning spans, with the leading head of the screw being essentially beyond the field of view of the CT scan. However, the software has since been updated to provide a more expansive view of the pelvis, including its anterior and lateral aspect. Moreover, Bederman et al. report the need for manual probing for all screws placed at depths that exceeded the robotic drill capacities (28 mm), which bears a risk of distal protrusion [27].

The described procedure calls for preoperative CT imaging, which is then used for both the planning and registration stages. While CT imaging increases patient radiation exposure as compared to more target-focused imaging on the operating table, it may lead to less radiation

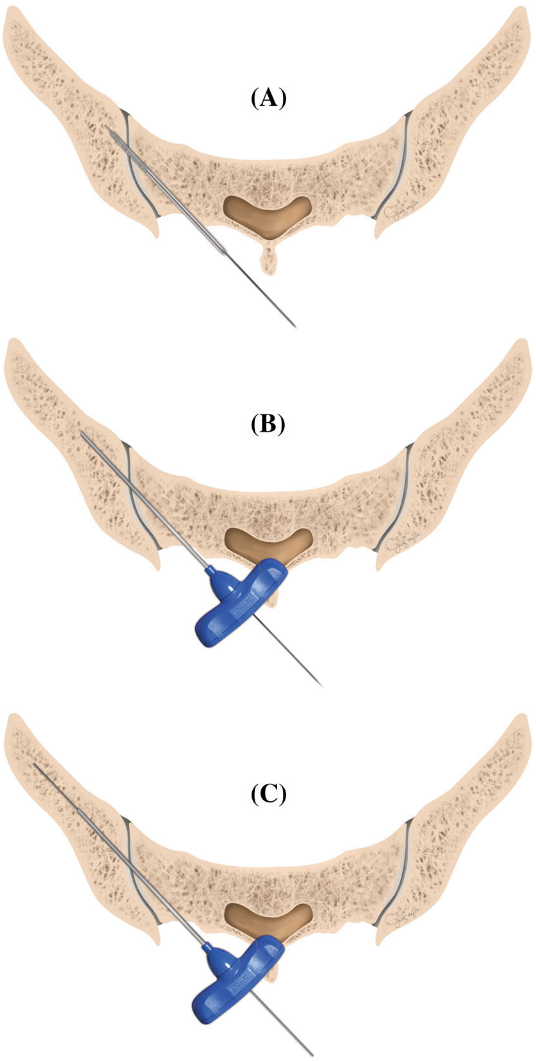

Fig. 2 **a** Insertion of K-wire into path drilled using renaissance robotic guidance system. **b** Advancement of the trajectory beyond the 28 mm pilot hole using a Jamshidi needle over the K-wire. **c** Advancement of the Jamshidi needle and K-wire further along the same path. Removal of the Jamshidi needle, tapping using cannulated tapper, and screw insertion

exposure for the entire surgical team, who bear a considerable radiation-associated occupational risk [28]. In fact, Hyun et al. [29] recently demonstrated in a randomized controlled study of 64 patients the inadequacy of standard radiation protection measures, underscoring the need for improved radiation-minimizing practices and procedures. In addition, the group reported a 62% reduction in surgeon radiation exposure during minimally invasive, robot-guided posterior lumbar interbody fusion procedures, as compared to those performed using an open approach. Furthermore, the described S2AI fixations are typically performed within the framework of longer cephalad fixations, which require the extensive views provided by CT images. Thus, the presented S2AI technique is performed as part of a longer fusion procedure, without requiring independent interventions and radiation sessions. Moreover, navigation based on CT-fluoro matching has been shown to improve visualization and overall surgical precision, alongside a 50% reduction in radiation exposure during vertebra-pelvic fixation procedures [30]. The technique suffers from risk of surgical tool skiving, which can be circumvented by avoiding uneven bony structures in the planning phase or by adequately preparing the anatomical landing area for tool docking on the bone [25, 31]. In addition, while the starting cost associated with acquisition and installation of the system is high, it may be offset by the overall life-cycle expenditure and more importantly, in centers with a high surgical load, by the improved clinical outcomes and reduced associated hazards.

In the present mini-case series of robotic-guided S2AI sacropelvic fixation procedures, all screws were optimally positioned without anterior and lateral protrusions, congruent with the preoperative plan. We suggest that it can be attributed to our Jamshidi needle technique as well as to software upgrade of virtual screws up to 80 mm long. Furthermore, a 90 mm screw was safely inserted using the Jamshidi needle technique even though the updated

Table 1 Patient information

Sex	Age	Indication for surgery	Number of fused levels	Diameter/length of screw	Pre-op SRS22	Postop SRS22
F	67	Spondylolisthesis, degenerative flatback deformity	4	8.5 × 80 mm (Rt.), 8.5 × 80 mm (Lt.)	2.2	3.5
F	69	Degenerative lumbar kyphosis	7	8.5 × 80 mm (Rt.), 8.5 × 80 mm (Lt.)	2.4	3.8
M	70	Degenerative lumbar scoliosis	7	8.5 × 80 mm (Rt.), 8.5 × 80 mm (Lt.)	1.5	3.1
F	60	Degenerative flatback deformity	15	8.5 × 90 mm (Rt.), 8.5 × 90 mm (Lt.)	1.25	4

Pre- and postop means pre- and postoperative, respectively software simulation limitations of virtual screws up to 80 mm long (Fig. 3).

While the current study has a patient sample of four, the improvement in SRS-22 scores was still significant statistically, as well as clinically, surpassing the 0.4 threshold for minimum clinically important difference [32]. Obviously, this cannot be attributed to the S2AI component alone, however, any chain is as strong as its weakest link, and the overall surgeries benefited the patients' disability index by 1.8 points on average.

In this four-patient case series of robotic-guided insertion of S2AI screws in adult patients undergoing corrective fusion surgery for spinal deformity, all eight trajectories were fully within the bone and accurately placed. Average surgery time per patient was 13 min with 5.3 s of fluoroscopy. No intra- or post-operative complications occurred. SRS-22 scores improved significantly, serving as an indicator of the feasibility of the approach and its non-inferiority to other approaches. Larger, comparative studies are needed to assess the reproducibility of these results and establish superiority over other surgical techniques.

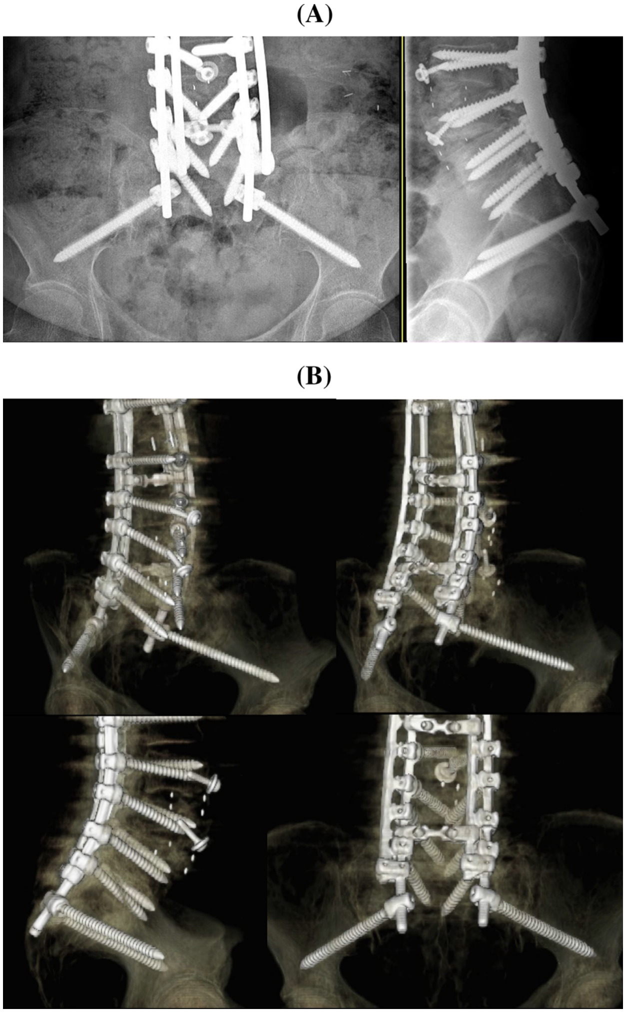

Fig. 3 Patient #4: a 90 mm screw was used. No cortical breach was observed on postoperative plain radiographs or 3D CT scan

Compliance with ethical standards

Conflict of interest None.

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