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Clinical Case Studies

New technique and case report: Robot-assisted intralaminar screw fixation of spondylolysis in an adolescent

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ABSTRACT

Introduction: Management of spondylolysis in adolescents is generally successful with conservative management. Uncommonly, surgical fixation is necessary for refractory cases. Direct repair with intralaminar screws is one commonly utilized technique. Recently, less invasive spinal procedures are becoming viable with the enabling of technologies, including robotics.

Case description: A 14-year-old baseball player and surfer presented with low back pain, diagnosed by MRI as bony edema and stress fractures of the posterior spinal elements. After 18 months, the pain was unresponsive to rest, physical therapy, and bracing. There was no radicular pain or neurologic symptoms. Computed tomography (CT) revealed bilateral, chronic nonhealing pars defects at L5. He underwent outpatient, robot-assisted percutaneous intralaminar fixation with hydroxyapatite-coated screws through a 2 cm skin incision.

Outcome: On postoperative day 1, the patient reported relief of his preoperative pain and he was ambulating without difficulty. At 2 weeks follow-up, the patient was completely pain free and surfing. At 2 months follow-up, low-dose CT demonstrated partial incorporation of the hydroxyapatite-coated screws, and the patient returned to sports. At 6 months follow-up, the patient had no pain and was swinging his baseball bat with full force. Low-dose CT revealed complete healing of the defects with full incorporation of the hydroxyapatite-coated screws.

Conclusions: A novel minimally invasive robotic percutaneous approach for direct spondylolysis repair using hydroxyapatite-coated screws is a potential surgical treatment option for non-healing pars defects in adolescent patients.

Introduction

Spondylolysis is a defect of the pars interarticularis of vertebrae, most commonly seen at L5 [1,2]. Historically, the incidence rate has been noted between 3% and 11% in the general population.[1–3]. In younger athletes, however, the incidence rate can be as high as 23% to 63% [2–6]. Though the initial treatment remains nonoperative with physical therapy, activity modification, and bracing, refractory pain can be managed with surgical fixation [1,7,8].

Modern analyses indicate that either a direct repair with intralaminar screws or a pedicle screw, rod, and laminar hook construct provide the best union rates and functional outcomes without complications [9–11]. Traditionally, these are open techniques with larger incisions and standard midline muscle dissection requiring inpatient hospital stay [7]. Therefore, given the recovery and morbidity of direct open repair, exhaustive preoperative conservative treatment must be tried before moving forward with surgery. Postoperatively, current literature supports that surgeons tend to recommend at least six months before returning to full sporting activities [11,12].

Spinal surgery has become the latest to join an increasing cohort of surgical fields evolving via robotics. Minimally invasive percutaneous approaches are becoming more readily available alternatives to open techniques, such as aforementioned intralaminar screw fixation for spondylolysis. The only published case of a robot-assisted minimally

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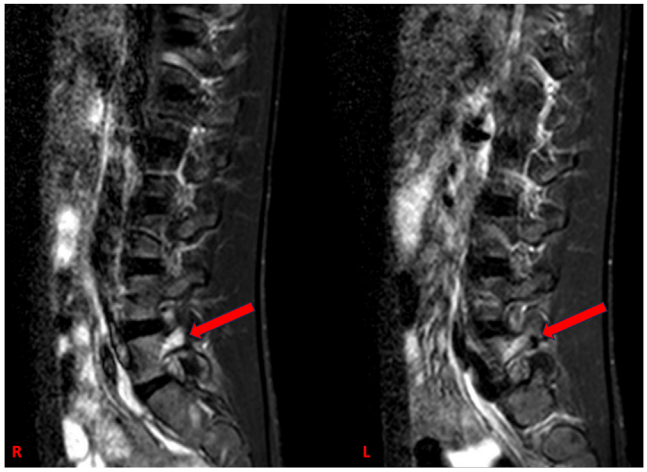

Fig. 1. Magnetic resonance imaging (MRI) sagittal views of L5 demonstrating bone marrow edema (red arrow) involving the posterior bony neural arches at the pedicle levels.

invasive direct repair of spondylolysis is in an adult patient [13]. We report a case of chronic, bilateral L5 spondylolysis in an adolescent athlete who returned to sports with radiographic evidence of screw incorporation just 2 months after outpatient, robot-assisted, minimally invasive percutaneous intralaminar fixation with hydroxyapatite-coated screws.

Case

Clinical presentation

An otherwise healthy 14-year-old, male surfer and baseball player presented to primary care with a history of progressive low back pain, believed to have originated after swinging his bat during a baseball game. The patient's pain was isolated to the lumbosacral region without radiation to the legs or buttock. He reported exacerbation of symptoms with running, swinging his bat, and bending forward at the waist. The physical exam was positive for limited range of motion during trunk flexion and extension with tenderness to palpation over the L4–L5 area posteriorly. Due to his pain coinciding with rotational movements, he was recommended to undergo magnetic resonance imaging (MRI) of the spine. The MRI demonstrated increased bony edema with a possible stress fracture of the posterior elements of L5 bilaterally (Fig. 1). The patient was advised to cease all high-impact activities and to use non-steroidal anti-inflammatory drugs as needed for pain. He was also prescribed a lumbosacral orthotic for pain.

During the next year, the patient's pain partially improved with activity modification, physical therapy, and recommended forms of active recovery such as swimming. He returned to baseball after a 9-month hiatus; however, the pain again worsened, and he continued to experience severe pain while base running and swinging his bat.

Thirteen months after his initial presentation, the patient was seen by sports neurology. He underwent X-rays of the lumbar spine, which demonstrated normal spinal architecture without evidence of segmental instability, spondylolysis, or spondylolisthesis (Fig. 2). Advanced imaging with a computed tomography (CT) scan of the lumbar spine demonstrated bilateral pars fractures at L5 with surrounding sclerosis, worse on the right than the left (Fig. 3). When fused with single photon emission computed tomography (SPECT) images, CT-SPECT demonstrated abnormal increased activity in the right lamina of L5, likely representing a non-healing pars fracture (Fig. 4). The left lamina of L5 and the pedicles and facet joints at all other levels appeared normal.

Management

One month later, the patient met with an orthopedic spine surgeon. Review of aforementioned imaging led to a diagnosis of chronic, bilateral L5 nonhealing spondylolysis. Multiple treatment plans were discussed with the patient and family including extended activity modification and physical therapy versus operative direct repair. The combination of an already prolonged trial of conservative management and the patient's desire to immediately return to sports yielded a decision for definitive operative management. The patient was deemed a candidate for percutaneous bilateral intralaminar screws since he had a large laminar surface area with minimal fracture gaps bilaterally, eliminating the need for bony debridement and grafting.

A plan was made for percutaneous internal fixation using the Globus Robot Excelsius Navigation with 2 intralaminar hydroxyapatite-coated screws crossing the fracture sites at L5. A final, repeat preoperative CT scan of the lumbar spine was used to aid trajectory planning with the robot. The goal was for both intralaminar screws to be placed through a

Fig. 2. Anteroposterior and lateral radiographs of the lumbar spine did not show evidence of segmental instability, spondylolisthesis, or spondylolysis.

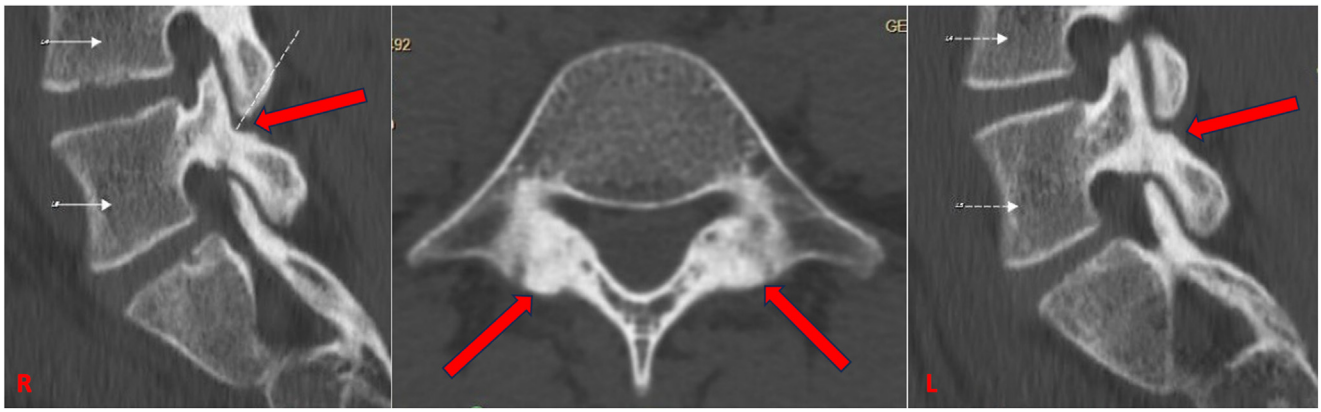

Fig. 3. Low-dose computed tomography (CT) scan of the lumbar spine demonstrating bilateral pars defects at L5 with surrounding sclerosis (red arrows), worse on the right than the left.

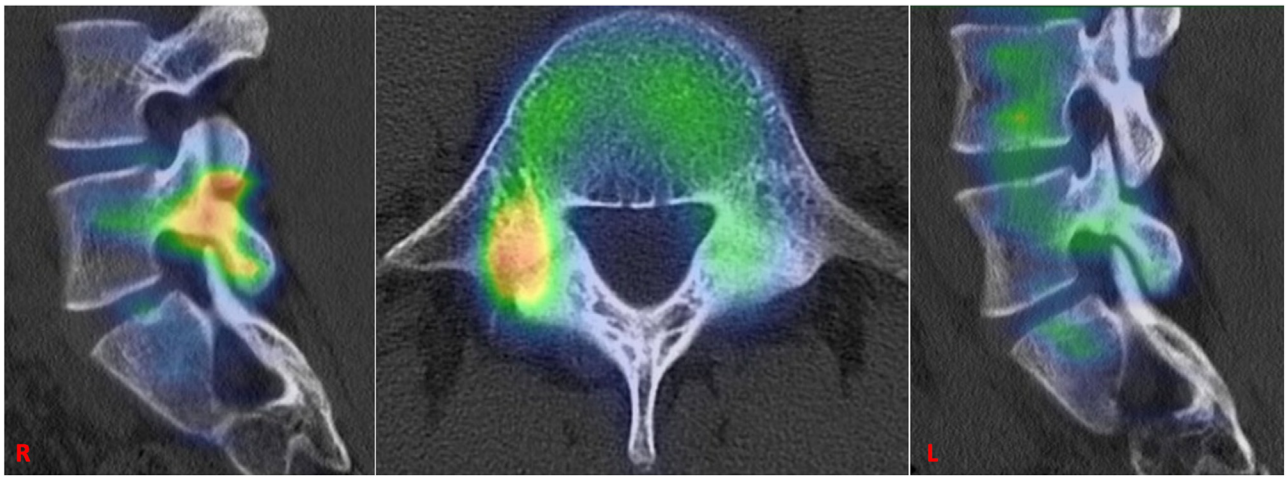

Fig. 4. Single photon emission computed tomography (SPECT) fused with prior CT scan demonstrating increased activity in the right lamina of L5.

single, posterior incision that would facilitate avoiding the facet joints, nerve roots, and dura (Fig. 5).

The patient was taken to the operating room nearly 18 months after his initial presentation to primary care. He was rolled prone onto the Jackson flat-top table, and a small stab incision was made over the right and left iliac crests for reference marker placement. The intraoperative fluoroscopic imaging was merged with the preoperative CT for use with the robot. The robot arm was moved into position, demonstrating that both screws would enter the skin at the same position, where a 2 cm-long vertical skin incision was made. A small, left-sided fascial incision was made, and a 4mm x 35mm hydroxyapatite-coated screw was placed through the left L5 pars defect, assessed for nerve root irritation with electromyographic stimulation, and verified positionally with intraoperative fluoroscopic images (Fig. 6). This was repeated on the right side.

The patient awoke from surgery without complication and was discharged home directly from the recovery unit the same day. His neurologic exam was symmetric and without deficits, and he was able to ambulate without difficulty the next day. He did not require opioid medications for pain control following discharge.

Outcome

At 2 weeks follow-up after surgery, the patient was symptom free aside from mild incisional soreness. He reported relief of pain during trunk flexion, extension, and rotation. The midline skin incision was healing well (Fig. 7). Postoperative AP and lateral X-rays at this time demonstrated well-positioned screws (Fig. 8). He reported that while surfing, he experienced brief, localized musculoskeletal pain in the low back; thus, he was advised to avoid surfing until his 2-month follow-up.

Five weeks after surgery, a low-dose CT scan demonstrated the appearance of a halo around the screws, indicating that the hydroxyapatite-coating hadn't yet facilitated bony ingrowth (Fig. 9). At nine weeks, a second low-dose CT scan, this time focused solely on L5, showed evidence of improved healing with partial incorporation of the hydroxyapatite-coated screws. The patient was recommended to gradually return to sports over the next month.

At 6 months follow-up, the patient had no pain whatsoever. He was playing baseball competitively, swinging with full force and running the bases without symptoms. Due to the family's desire for final confirmation imaging, the patient underwent a third low-dose CT, focused on L5, which showed hydroxyapatite-coated screws fully incorporated and in good position, and near complete healing of the fractures (Fig. 10).

Discussion

Though the exact pathophysiology of adolescent spondylolysis remains a matter of discussion, it is generally described as a multifactorial consequence of repetitive microtrauma producing a defect in a weakened or dysplastic pars interarticularis [14–16]. Adolescent athletes are particularly susceptible due to excessive mechanical stress secondary to repetitive hyperextension of the lumbar spine. As the lumbar spine extends and rotates, the inferior articular process of the superior vertebrae impacts the pars interarticularis of the inferior vertebrae, which

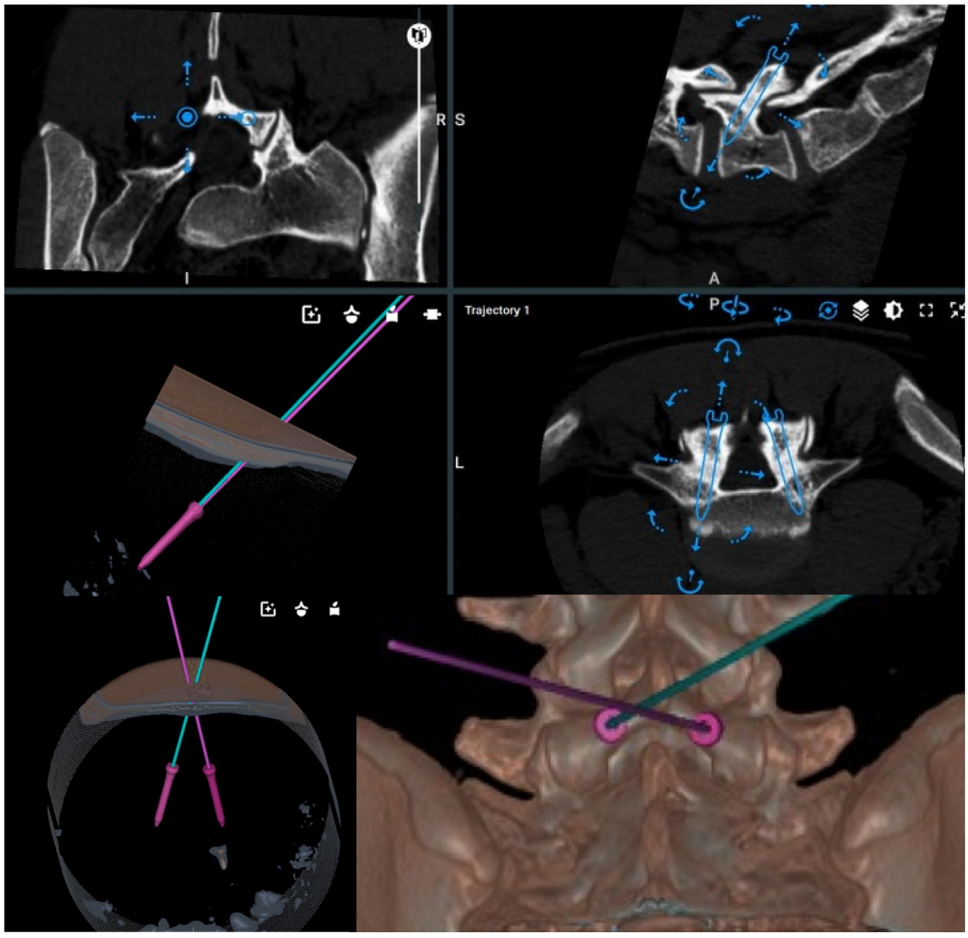

Fig. 5. Preoperative planning was performed with the Globus Robot Excelcius Navigation software for placement of 2 intralaminar screws to (1) traverse the spondylolysis with significant threads on both sides of the fracture (2) avoid injury to the facet joints, (3) avoid injury to nerve roots and dura and (4) allow for a single posterior, midline incision.

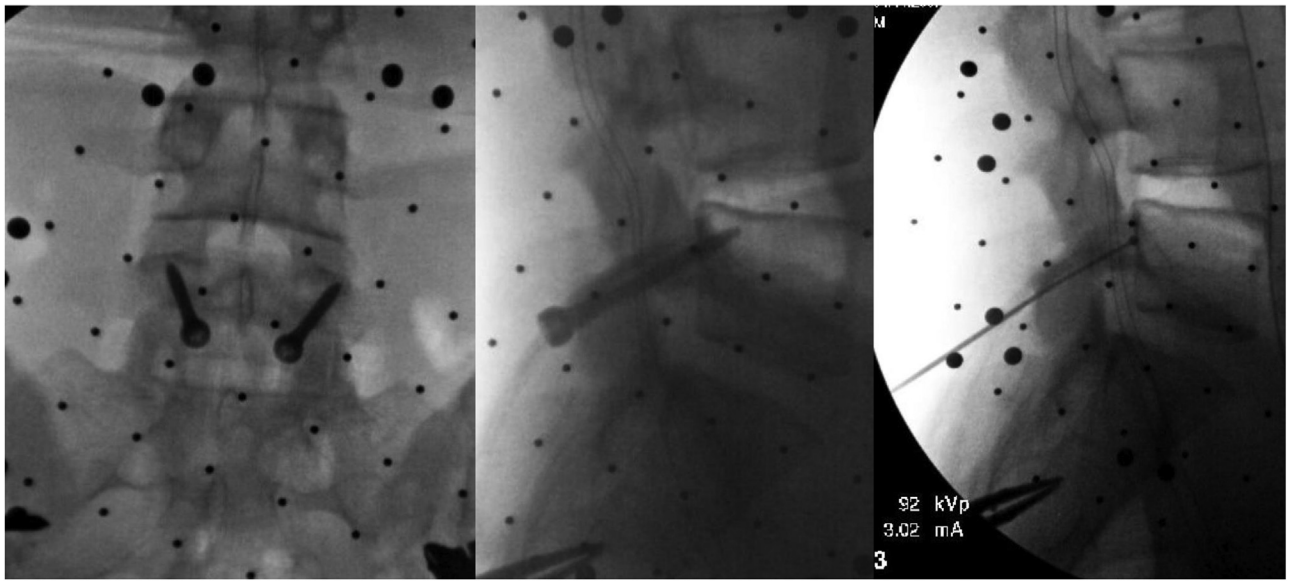

Fig. 6. Intraoperative fluoroscopic images used to verify position of screws.

Fig. 7. A 2 cm posterior, midline incision healing at 2 weeks follow-up after surgery.

over time, can weaken the pars and lead to microfractures [17] This mechanism is likely responsible for the clinical findings in our patient, and it underscores the importance of considering spondylolysis in adolescent athletes presenting with low back pain even if initial plain film radiographs are negative.

For most patients with spondylolysis, symptoms improve with conservative, non-operative treatments. Choi et al. [1] retrospectively reviewed 201 adolescent athletes with spondylolysis and found that 98% returned to sports with conservative management. However, surgical management may be recommended for patients with continued clinically significant limitations, including persistent pain after a trial of conservative treatments. Our patient's symptoms persisted despite 18 months of activity modification and physical therapy. At that time, additional conservative approaches were considered, but his desire to immediately return to sports directed decision making towards surgery.

The goals of surgical intervention in adolescent spondylolysis are to alleviate pain after continued failed cycles of nonoperative treatments. Several studies have highlighted the benefits of using an intralaminar screw fixation technique, which allows for direct repair of the pars defect without spinal fusion [9–11]. The technique, developed by Buck et al. [18] in 1970, preserves natural lumbar motion better than the pedicle screw, rod, and laminar hook construct [19] and has been shown to allow athletes with spondylolysis to efficiently return to sports [12,20].

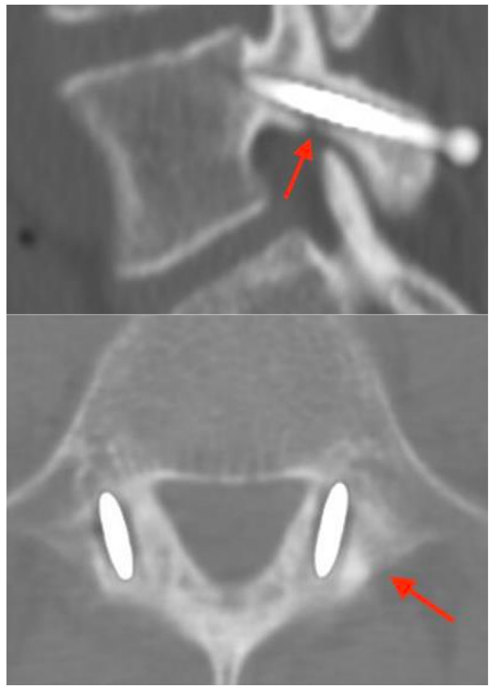

Fig. 9. Low-dose CT scan of L5 demonstrating the appearance of a halo (red arrows) around the hydroxyapatite-coated screws with minimal healing at five weeks follow-up after surgery.

In 2003, Debnath et al. [20] reported a 95% return to sports in athletes undergoing Buck's repair for spondylolysis. Similarly in 2014, Menga et al.[12] reported a 76% return to sports at six months follow-up in adolescent athletes after undergoing Buck's repair.

The current report illustrates a Buck's repair utilizing the Globus Robot Excelsius Navigation to facilitate an outpatient, percutaneous approach with a smaller, 2cm midline muscle-sparing incision, a means to improve on the existing open approach [7]. Importantly, a percutaneous approach was selected over open bony debridement due to the patient's small fracture gaps and minimal sclerosis seen on imaging (Fig. 3). The smaller incision minimized soft tissue dissection, which has been shown to decrease blood loss, perioperative infections, muscle atrophy, and other complications [21–23]. Tovar et al. [21] in 2022 systematically reviewed 11,113 patients undergoing spinal surgery and found that robot-assisted lumbar spine surgeries were associated with a smaller risk of inaccurate screw placement, fewer reoperations, and fewer perioperative

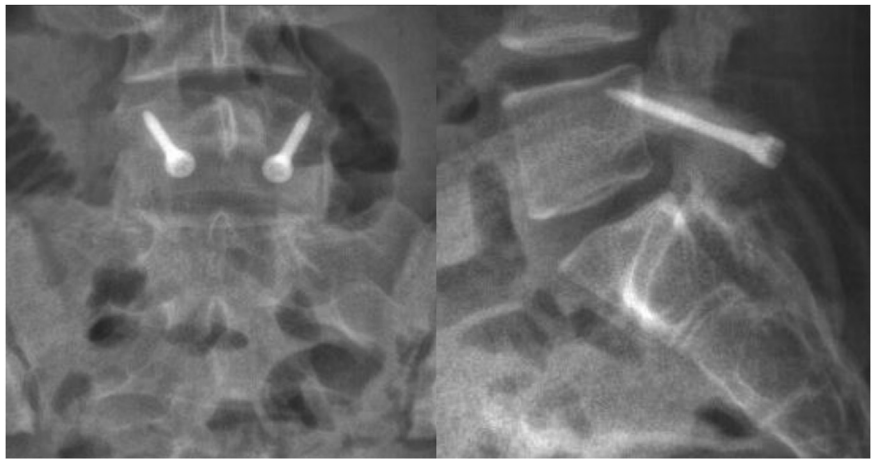

Fig. 8. Postoperative anteroposterior and lateral X-rays demonstrating well-positioned screws at 2 weeks follow-up after surgery.

Fig. 10. Low-dose CT scan of L5 demonstrating near complete healing of pars defects with incorporation of hydroxyapatite-coated screws bilaterally at six months follow-up after surgery.

complications (p<.0001). Furthermore, using the robot helps ameliorate many visualization and drill manipulation challenges seen in posterior spinal surgery [13]. The robotic arm allows for accurate positioning to avoid the facet joints bilaterally, consistent steadiness, and repeatability in surgery, all of which provide advantages to the traditional fluoroscopic approach [21,24]. Here, the robotic technology was used to exploit those advantages and create an ideal screw plan that utilized a single shared incision, maximal screw length and width, avoidance of the midline spinous process, and orthogonality to the fracture cleft.

While cannulated screws with a guidewire are the cornerstone of minimally invasive surgery, a robot allows for the use of solid screws, which have been repeatedly shown to be stronger than their cannulated counterparts [25–27]. Additionally, the solid screws were coated in hydroxyapatite, the most significant inorganic compound in bone tissue [28]. This coating has been found to significantly increase bonding strength at the bone-implant interface during spinal surgery, and histologic analysis of hydroxyapatite-coated hip prostheses has shown that bony ingrowth with osseous integration occurs as early as 10 days following implantation [29,30]. We therefore hypothesized that these screws would improve fusion, especially if there are indications of even minimal sclerosis in the fracture gap. This approach was chosen over open bony debridement and grafting given the small fracture gap and a strong potential for significant bony contact. Finally, lag screws were avoided to minimize the risk of loosening and loss of compression secondary to the bending, shearing, and torsional forces that would continue to act on this adolescent athlete's spine. Having significant threads on both sides of the fracture gaps would also augment healing.

The patient underwent 3 low-dose focused postoperative CT scans to assess hydroxyapatite-coated screw incorporation and fusion, which should only be judiciously recommended in pediatric patients due to the associated radiation risks [31]. The patient's family requested final imaging at 6 months to verify healing after a long, 2-year struggle with the injury. If further computed tomography must be done, it is important to isolate the scan to the affected region, as was done in this case at L5.

We believe the percutaneous nature of robotic surgery along with the utilization of hydroxyapatite-coated solid screws helped facilitate our patient's return to sports in just 2 months after surgery with strong radiographic evidence of healing and screw incorporation (Fig. 10).

Conclusion

This is the first reported case of an adolescent patient who successfully underwent outpatient, percutaneous intralaminar screw fixation with the use of a robot, significantly expediting his pain relief and return to sports.

Informed Patient Consent

Complete written informed consent was obtained from the patient for the publication of this study and accompanying images.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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