Case Report

Minimally invasive robotic cervicothoracic fusion: a case report and review of literature

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Abstract: Minimally invasive surgery (MIS) of the posterior cervical spine with robotic assistance has recently emerged to treat degenerative disc disease. Robotic arms and 3D neuronavigation with preoperatively planned placement are used to achieve real-time intraoperative guidance, reducing screw malposition through increased accuracy and stability. This results in decreased blood loss, postoperative pain, and quicker recovery time compared to other techniques. We aim to demonstrate a novel technical approach to posterior cervical spine fusion using robotic assistance and discuss its advantages. In a patient with right hand weakness and a right paracentral disc herniation of the cervicothoracic spine, we performed a MIS percutaneous and robotically assisted posterior spinal fusion at C7–T2, with complete C7–T1 and T1–2 right-sided facetectomies and also a T1–T2 discectomy. Preoperative software planning and a robotic platform attachment configuration was used. There was immediate postoperative improvement in upper extremity strength and the patient was discharged without complications. Postoperative imaging confirmed accurate hardware placement, and follow-up at both 3- and 4-month confirmed improved upper extremity strength with sensation intact throughout. MIS robotic posterior cervicothoracic fusion can effectively be used to improve patient outcomes. Further implementation of robotic assistance during cervical fusion in larger studies is needed to further evaluate its effectiveness.

Keywords: Minimally invasive surgery (MIS); robotic spinal fusion; cervicothoracic fusion

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Introduction

Minimally invasive surgery (MIS) of the posterior cervicothoracic spine has recently emerged to treat cervical myelopathy and radiculopathy through spinal fusion. Implementation of 3D neuronavigation and robotic assistance have made smaller incisions possible while also reducing muscular injury, which has decreased postoperative pain and recovery time compared to traditional open techniques (1-4). MIS techniques also significantly reduce intraoperative blood loss while open techniques result in significant blood loss and lengthy recovery times (2,3,5-9).

Robotic-assisted fixation techniques further reduce blood loss and increase pedicle screw insertion accuracy compared to MIS techniques alone (10,11). The first reported case of posterior upper cervical spine surgery using robotic assistance was performed by Tian, where a C1–2 transarticular screw fixation was safely performed under guidance of the TiRobot with accuracy and without complications (10). Another study by Fan *et al.* further demonstrated accurate cervical screw placement and reduced blood loss using robotic assistance (11).

We report a case of a male patient who presented with progressive right hand and forearm weakness with corresponding atrophy. Spinal canal stenosis, cord compression, foraminal stenosis, and a right paracentral disc herniation was discovered upon magnetic resonance imaging (MRI). A MIS percutaneous robotic cervicothoracic

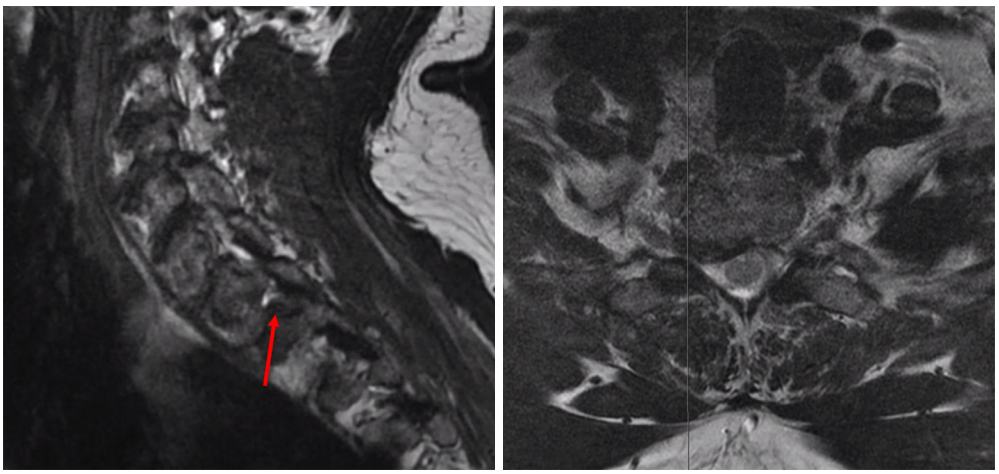

Figure 1 Sagittal and axial preoperative MRI T2-weighted sequences showing a large T1–2 disc herniation impinging upon the exiting T1 nerve root (red arrow). MRI, magnetic resonance imaging.

fusion was performed, and it successfully recovered right hand and forearm strength without residual sensory loss. We discuss the findings of our novel technical description and also provide a narrative review of the current literature to identify previous cases which successfully used a MIS cervicothoracic technique.

We present the following case in accordance with the CARE reporting checklist (available at http://dx.doi.org/10.21037/acr-20-149).

Case presentation

History and presentation

A 68-year-old male presented with 6 months of progressive right hand and forearm weakness. His hand was caught in a claw-like position with atrophy of the thenar eminence and forearm. A neurological examination demonstrated decreased strength in the right upper extremity graded as 2/5 for the interossei, opponens pollicis, flexor pollicis brevis, and abductor pollicis brevis. The patient had no clinical signs of myelopathy. A cervical MRI at presentation showed foraminal stenosis at C7–T1 and a right-sided disc herniation with foraminal impingement at T1–T2 (*Figure 1*). The risks of the procedure and alternatives were discussed, and surgery was determined to be the best course of treatment to minimize further functional loss and maximize his chances of recovering strength.

Robotic software planning

Preoperative planning software was utilized to pre-plan trajectories for all screws to allow for directed intraoperative rod placement and to ensure anatomical placement of all instrumentation (*Figure 2*).

Intraoperative positioning and robotic platform attachment

The patient was positioned prone. Two small stab incisions were made over the C7 and T1 spinous processes and two spinous process pins were placed under fluoroscopic guidance. This was then attached to the navigated spinal robotics platform. Once this was completed, the navigated spinal robotic platform was then registered to the patient with a series of X-rays and an optical survey scan.

Intraoperative robotic technique

A right-sided paraspinal incision was made with the guidance of the robotics platform and the right then left-sided C7, T1 and T2 pedicle tracts were then drilled and tapped. A minimal access retractor was then placed for exposure of the right sided C7–T2 facets. A full C7–T1 and T1–2 facetectomy was performed with full visualization of the exiting C8 and T1 nerve root from its origin at the level of the dura out to the foramen, followed by a T1–T2 discectomy. Bone graft was laid, and rods were then secured bilaterally (*Figure 3*).

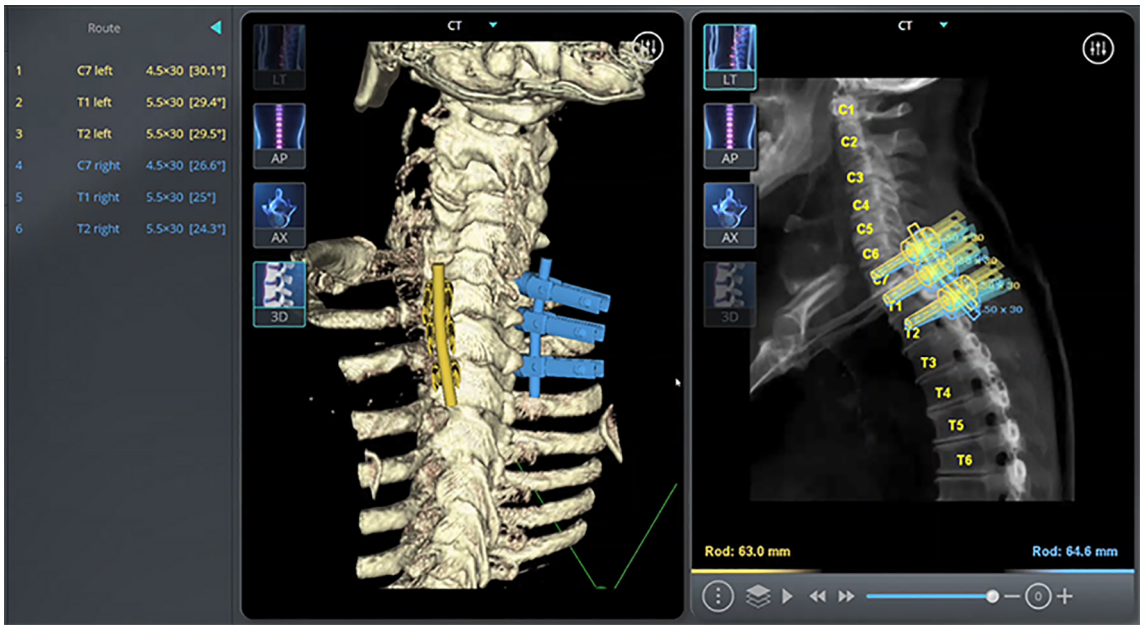

Figure 2 Preoperative software showing the surgical robotic plan with a construct design tailored for a minimally invasive incision and application.

Outcome

There was immediate postoperative improvement in the patient's upper extremity strength and postoperative imaging confirmed accurate hardware placement. The patient was discharged without complications. At 6 months follow-up there was improvement in hand grip strength to a 4–/5 with sensation intact throughout (*Figure 4*). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patient for publication of this report and any accompanying images.

Discussion

A review of the English-language literature using the PubMed database for published case reports and case series from earliest date until present demonstrated 18 reports ranging in publication year between 2005 to 2019, that described patients who underwent percutaneous or MIS posterior cervicothoracic fixation between C1–T4 (*Table 1*). There was a total of 217 patients (range 16–89 years old, 119 men and 98 women) in reports where this information was available who underwent MIS surgery to correct the conditions including but not limited to cervical fractures, tumors, and discopathy (*Table 1*) (1-9,12-19). Surgical techniques included pedicle screw or lateral mass fixation (17-19), stand-alone screw fixation (2), transpedicular osteosynthesis (6), gallie fusion (8), and DTRAX facet implant (5). Average operation times were reduced compared to open techniques and ranged from 90 to 298 minutes when reported (2,20). A majority of cases reported pain reduction compared to open techniques. Complications included postoperative quadriplegia from epidural hematoma (20), clinically significant pedicle screw deviation/backout (5,13), conversion to open surgery (18), and postoperative infection (15,18).

Shift towards MIS cervical spine surgery

Cervical MIS techniques reduce tissue trauma, blood loss, infection rate, and operative time without compromising accuracy or stability of fixation compared to traditional techniques (2,6,20). Decreased postoperative pain following MIS surgery in comparison to traditional open techniques can be attributed to the reduced surgical stress of muscle stripping and retraction accomplished through use of small MIS exposures and access through tubular retractors (1,13,20). Minimally invasive approaches also allow

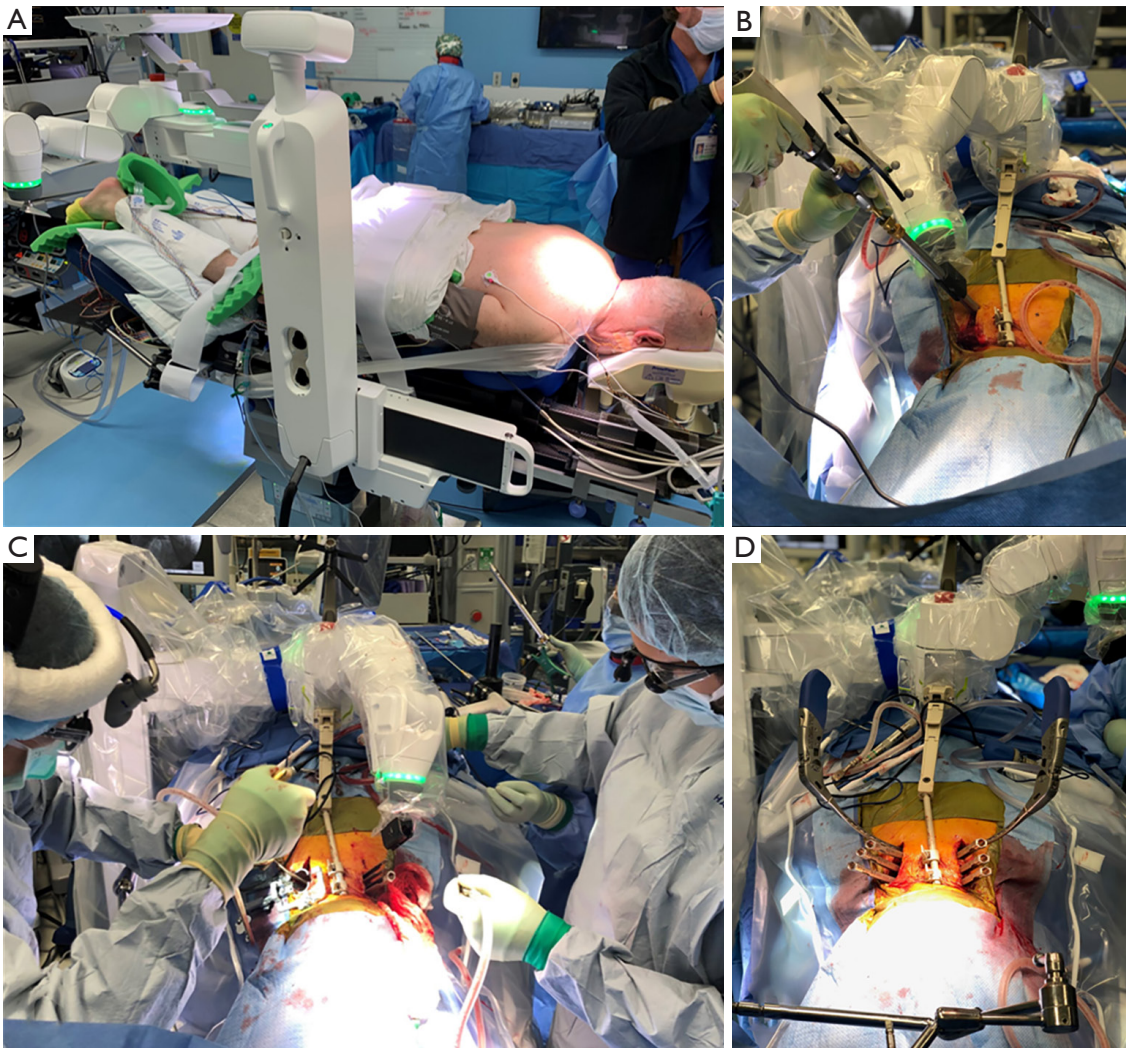

Figure 3 Intraoperative robotic platform positioning, attachment, workflow, and surgical field view. (A) Patient positioning with the robotics platform. (B) Rigid attachment of the robotics platform to the spine for increased rigidity and stability. (C) Workflow of the right-sided minimally invasive facetectomy and discectomy with left-sided placement of instrumentation. (D) Surgical field view showing minimally invasive rod placement.

earlier ambulation and discharge (4,14), which may ultimately lead to decreased cost and complications.

Robotic MIS

Recent advances in technology and technique strive to improve stability, accuracy, and consistency during pedicle screw placement. These can be accomplished during MIS approaches with use of surgical planning, preoperative imaging, and real-time neuronavigation techniques to avoid screw malposition and potential injury to vertebral arteries or nerve roots (13,20). Robotic assistance further increases the capabilities of MIS by using computer-assisted navigation that incorporates cameras, imaging, robotic arms, and tracking of patients/robotic arms (10,11). Although open exposures have the advantage of a larger visual field and ease of rod placement, the need for direct visualization is reduced as the navigated robotic arm allows screw trajectory to be confirmed with overlayed preoperative imaging that contains pre-planned targets, and the arm maintains a stable and rigid tubular retractor position as to avoid deviation during screw placement. As demonstrated

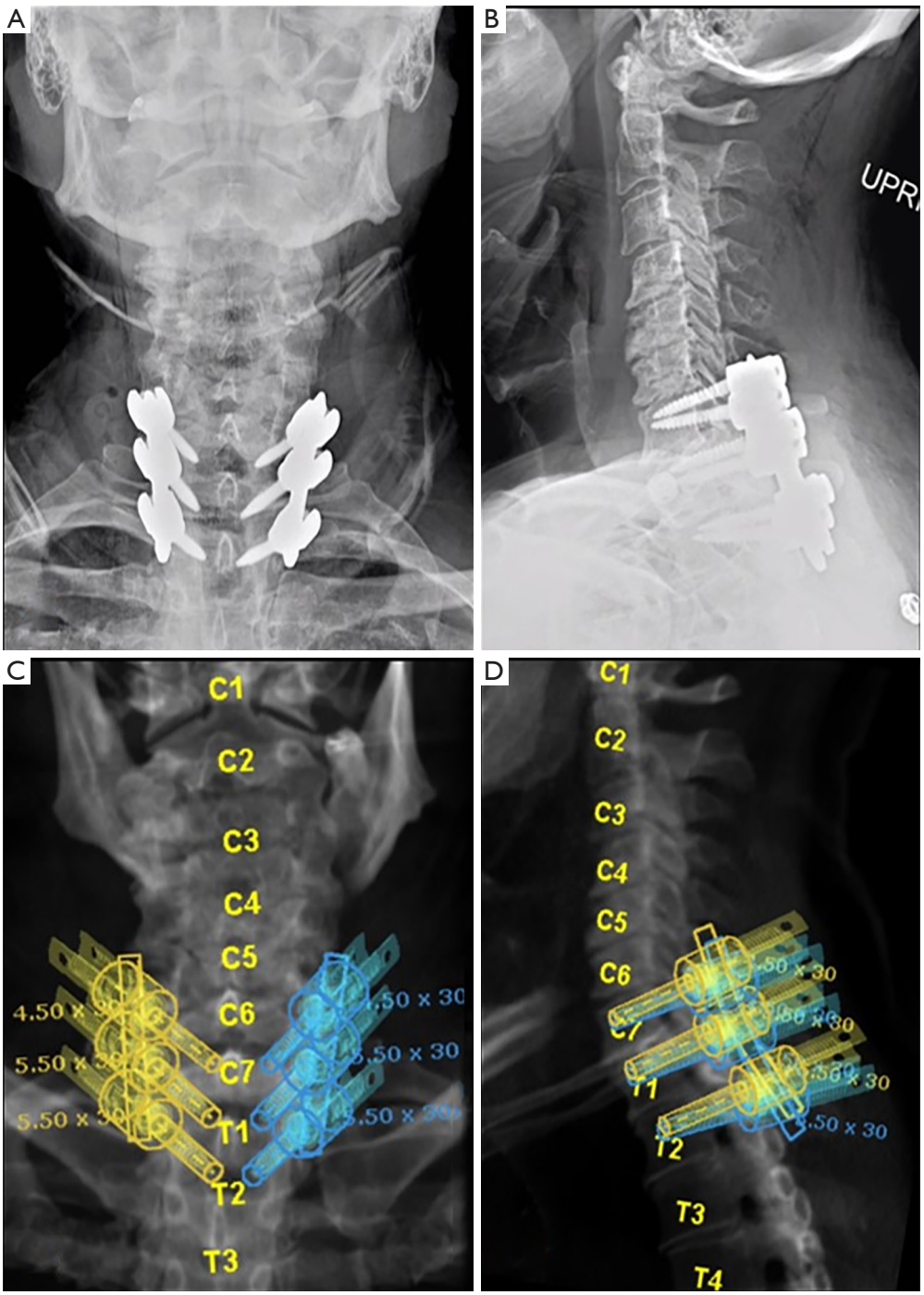

Figure 4 Comparison of the preoperative software plan imaging to postoperative plain films showing good accuracy of the predictive algorithm. (A) AP plain film showing C7–T2 instrumentation. (B) Lateral plain film showing C7–T2 instrumentation. (C) AP preoperative software plan. (D) Lateral preoperative software plan. AP, anteroposterior.

Table 1 Summary of previous reports of posterior MIS or percutaneous cervicothoracic fixation between C1–T4

Publications	Age	Sex	Pathology	Spinal levels	Avg/Op. (min)	Surgical technique	Outcome	Complications
Soliman *et al.* [2019] (4)	35–76	M/2	HF	C1–C3	–	Surgical unilateral transfixation with MIS percutaneous screw placement using 3D neuronavigation & bidirectional intraoperative fluoroscopy	Both patients reported immediate pain relief, quickly mobilized & discharged	None
Lee & Park [2019] (12)	77	M/1	ID	C6–C7	–	Cervical pedicle screws inserted bilaterally with a freehand technique through tubular retractors with subsequent posterolateral fusion followed by anterior interbody fusion	Patient immediately able to sit postoperatively without serious neck pain and ambulation was possible in 1 day, VAS was 1 point at 6-month follow-up, bilateral semispinalis cervicis was preserved	None
Lvov *et al.* [2019] (2)	17–81	M/27, F/11	OF; JF; MF	C1–C2	90	Posterior MIS transarticular stand-alone screw fixation of cervical spine	Statistical analysis revealed reduced blood loss, shorter duration of surgery, & lower postoperative pain compared to posterior midline approach	None
Kovari *et al.* [2017] (6)	35	F/1	HF	C2	98	Direct transpedicular osteosynthesis of odontoid process through posterior MIS transmuscular approach guided by C-arm fluoroscopy	Low blood loss, patient remained neurologically intact, no evidence of re-dislocation, instability, or implant failure upon follow-up	None
Soriano-Solís *et al.* [2017] (7)	71–73	F/2	DD; SS	C3–C7	298	MIS single-door plate laminoplasty with lateral mass screw fixation of unstable segment using tubular retractors, under fluoroscopic guidance	Low blood loss, no signs of cervical instability or device failure on follow-up	None
Sugimoto *et al.* [2017] (3)	39–71	M/2, F/4	TM	C2–T2	234	MIS cervical pedicle screw fixation via posterolateral approach using spinal navigation and fluoroscopy	Decreased surgical time and blood loss compared to conventional pedicle screw fixation	Postoperative quadriplegia from hematoma
Kantelhardt *et al.* [2016] (9)	48–89	M/3, F/4	HF; OF	C1–C6	106	Iso-C3d-based image guidance for percutaneous unilateral one-level lag screw placement into pedicles, isthimi, and lateral masses	Low blood loss, 3.8-minute average X-ray time, all cases were performed with correct screw placement	None
Komatsubara *et al.* [2017] (13)	18–89	M/30, F/7	LMF; FD; BF; SL	C2–T1	165	MIS cervical pedicle screw fixation via posterolateral approach using spinal navigation and fluoroscopy	Decreased average surgical time from 217 minutes in conventional fixation to 165 minutes in MIS fixation, decreased average intraoperative bleeding from 560 mL in conventional fixation to 140 mL in MIS fixation, clinically significant screw deviation was significantly lower in MIS group	Clinically significant pedicle screw deviation

Table 1 (*continued*)

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Publications	Age	Sex	Pathology	Spinal levels	Avg/Op. (min)	Surgical technique	Outcome	Complications
Wu *et al.* [2016] (8)	47–72	M/3 F/2	JF; OF; AADL	C1–C2	–	Mini-open posterior C1/2 gallie fusion for high-riding vertebral artery, to supplement anterior atlantoaxial transarticular screw fixation	Low blood loss, no screw breakage was observed & bone union was achieved in all patients on follow-up and symptoms were resolved	None
Buchholz *et al.* [2015] (14)	46–67	M/3 F/2	HF	C2	–	Percutaneous MIS 3D fluoroscopy & navigation-guided reduction and internal screw fixation of odontoid process	Immediate postoperative ambulation, dynamic imaging demonstrated a stable construct	None
McCormack *et al.* [2013] (5)	40–75	M/23 F/37	FS; DD	C3–C7	–	Bilateral single-level percutaneous posterior cervical fusion using facet implant DTRAX system	Neck disability index (F2, V2) and VAS scores significantly improved, 93% of patients had inter-facet bridging trabecular bone at follow-up anterior disc height significantly decreased after 1 year and posterior disc height increased at 6 months, no significant decrease in foraminal height/width at adjacent levels after 1 year	Partial screw backout at 6 months
Schaefer *et al.* [2011] (15)	25–79	M/6 F/9	TM; INF; DD; TR	C2–T4	186	Multi-level percutaneous instrumentation of cervicothoracic spine using transpedicular screw fixation under fluoroscopic control	76.4% of 72 screws placed accurately, 23.6% had perforations of pedicle wall, critical breaches or transverse foramen narrowing occurred in 12.5%, no conversions from percutaneous to open surgery, 2–3 cm incision sufficient for three adjacent level fixations, patients walked 1 day after surgery	Infection
Holly *et al.* [2010] (1)	39–64	M/5 F/1	OF	C1–C2	–	MIS C1/2 fusion using bilateral segmental atlantoaxial fixation with expandable tube retractor	Low blood loss, solid fusion achieved in all patients, no hardware malposition in four out of six patients on CT imaging	None
Scheufler & Kirsch [2007] (16)	62–83	M/6 F/5	SPD; SS; FS	C2–C7	157	Multi-level microendoscopic percutaneous instrumented fusion under fluoroscopic guidance	All patients demonstrated correct screw positioning on CT imaging, adequate neural decompression was achieved and there was significant or complete reduction in radicular or myelopathic symptoms	None

Table 1 (*continued*)

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Publications	Age	Sex	Pathology	Spinal levels	Avg/Op. (min)	Surgical technique	Outcome	Complications
Joseffer *et al.* [2006] (17)	35	F/1	OS	C1–C2	–	MIS placement of lateral mass and pedicle screws through tubular retractors under fluoroscopic guidance	Discharged on postoperative day 2, patient remained neurologically intact with complete resolution of symptoms on follow-up	None
Wang & Levi [2006] (18)	18–72	M/8 F/10	TM; PA; FAD; BF; VO	C3–C7	–	MIS bilateral lateral mass screw placement through midline incision and tubular dilator retractors under lateral fluoroscopy	All patients achieved successful bony fusion and the average blood loss was 112 mL, inpatient hospital stays averaged 3.7 days	Conversion to open surgery, infection, iliac crest pain
Fong & Duplessis [2005] (19)	16–64	F/2	FAD; BF	C5–C6	–	MIS lateral mass screw and plate fixation/fusion using a tubular dilator retractor system (METRX), paired with anterior fusion	Minimal blood loss with no neurological deficits in both patients	None

HF, hangman's fracture; OF, odontoid fracture; JF, Jefferson fracture; MF, multiple fractures; TM, tumor; DD, disc degeneration; SS, spinal stenosis; FS, foraminal stenosis; AADL, atlantoaxial dislocation; INF, infection; TR, trauma; VAS, visual analogue score; CT, computed tomography; MIS, minimally invasive; ID, infectious discitis; Avg/Op., average operative time; LMF, lateral mass fracture; FD, fracture-dislocation; BF, burst fracture; SL, spondylolisthesis; SPD, spondylosis; PA, pseudoarthritis; FAD, facet dislocation; FF, facet fracture; VO, vertebral osteomyelitis; OS, os odontoideum.

in the preoperative plan, spinal robotics allows for planning of the entirety of a construct with insertion points and trajectories, rather than individual screws that are then rodded together. This makes rod passage more feasible through a smaller incision in comparison to traditional MIS techniques, which speeds up workflow resulting in reduced overall operative time.

Robotic assistance for spinal fixation has already been established as a safe technique in lower spine surgeries (10,11). A recent prospective randomized control study comparing fluoroscopy-assisted versus robot-assisted cervical screw fixation was performed by Fan *et al.* (11). They found that patients with robot-assisted fixation had significantly better screw placement accuracy, and the robot-assisted group experienced significantly less blood loss and shorter post-operative lengths of stay (11). Despite the benefits of robotic assistance, difficulties with registration/trajectory and anatomical variations that are undetected through preoperative imaging could lead to complications (10,11). We used a Maxor X system and did not encounter any issues with registration which allowed successful completion of this minimally invasive fusion without any technical shortcomings or complications. Adoption of robotic assistance in posterior cervicothoracic fusion is still in its early stages so further studies are required to determine its efficacy.

Conclusions

MIS robotic posterior cervicothoracic fusion can effectively be used to achieve surgical decompression and instrumentation resulting in reduced blood loss and shorter post-operative length of stay. We report here an operative technical description and review of the literature which demonstrates these characteristics while also highlighting areas for future improvement. Further implementation of robotic assistance in larger studies is needed to further evaluate its effectiveness.

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Footnote

Reporting Checklist: The authors have completed the CARE reporting checklist. Available at http://dx.doi.org/10.21037/acr-20-149

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at http://dx.doi.org/10.21037/acr-20-149). Dr. MHP reports personal fees from Medtronic as a consultant, outside the submitted work. The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patient for publication of this report and any accompanying images.

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