Surgical Technique

Surgical technique of combined minimally invasive anterior column realignment at L1–L2 with open extension of prior fusion

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Abstract: Surgical correction of fixed kyphotic deformity or severe sagittal imbalance traditionally involves three column osteotomies, which are associated with high morbidity rates. Anterior column realignment (ACR) has emerged as a minimally invasive alternative for restoring segmental lordosis. This technique involves a lateral approach and release of the anterior longitudinal ligament (ALL), followed by placement of a hyperlordotic interbody cage. In this study, we present a successful case of minimally invasive ACR for the treatment of flatback deformity and adjacent segment disease in a patient with prior L2–S1 fusion. Imaging revealed a flatback deformity, sagittal vertical axis elevation, and spinopelvic disharmony. The patient underwent a multistage procedure involving a lateral retropleural approach for ACR and interbody fusion, followed by open posterior instrumented fusion and vertebroplasties. Postoperatively, the patient experienced significant pain relief and improvement in lumbar lordosis, pelvic tilt, and pelvic incidence-lumbar lordosis mismatch. ACR combined with posterior release allows for manipulation of all three spinal columns, leading to spine reconstruction and improved spinopelvic harmony. We discuss the advantages of ACR, including its minimally invasive nature and potential benefits for patients with sagittal deformities. The presented surgical technique demonstrates the feasibility and efficacy of minimally invasive ACR in addressing flatback deformity and adjacent segment disease.

Keywords: Anterior column realignment (ACR); minimally invasive surgery; deformity

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Introduction

For the surgical correction of a fixed kyphotic deformity or severe sagittal imbalance, three column osteotomies have traditionally been employed for large degrees of correction (1). These surgeries are challenging and carry high morbidity rates (2). Anterior column realignment (ACR) was developed as a less invasive procedure for restoring segmental lordosis (3). The ACR procedure involves a minimally invasive lateral retroperitoneal retropleural approach (depending on level) to perform a complete discectomy and deliberate release of the anterior longitudinal ligament (ALL) either through sequential dilation or direct sectioning (1,3). Following release of the ALL, a hyperlordotic interbody cage is then placed into the disc space and fixed to the vertebral body with one or two screws. Currently cages up to 30 degrees are used, with polyetheretherketone (PEEK), titanium, and

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hybrid cages available. ACR is thus an anterior column lengthening procedure, in contrast to a posterior shortening procedure of a pedicle subtraction osteotomy (4). The presented surgical technique demonstrates successful use of a minimally invasive ACR to treat flatback deformity and adjacent segment disease (ASD). We present this article in accordance with the SUPER reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-23-45/rc).

Preoperative preparations and requirements

A 56-year-old woman with no significant medical comorbidities, who had undergone previous L2–S1 fusion surgery 7 years prior, presented to clinic with complaints of back and radiating right leg pain. Her back pain was most bothersome, and the right leg pain radiated from her low back into her right hip and lateral thigh consistent with an L5 radiculopathy. Her symptoms were refractory to non-operative management including lumbar physical therapy, epidural steroid injections, and oral pain medications. The pain was affecting her quality of life and her activities of daily living, and she desired an intervention. On examination, she was neurologically intact with full strength and no abnormal sensation or reflexes.

Her imaging was notable for her previous L2–S1 fusion that was now a flatback deformity, with a lumbar lordosis of 21 degrees. Adjacent segment disease was present at L1–L2. Her sagittal vertical axis was slightly elevated at 6.2 cm, she had a pelvic incidence to lumbar lordosis mismatch of 25 degrees and an elevated pelvic tilt of 30 degrees, suggesting compensatory retroversion of her pelvis in order to maintain appropriate sagittal alignment. Her computed tomography (CT) scan demonstrated solid union between L2 and S1. Severe degenerative disc disease was noted at L1–L2 and T11–T12. Magnetic resonance imaging did not show significant neural compression.

Based on the patient's symptoms and imaging findings, she was offered a multistage procedure with a minimally invasive lateral surgery with open posterior extension of fusion. The first stage was L1–L2 minimally invasive lateral retropleural approach for anterior column realignment and interbody fusion. The second stage was open posterior instrumented fusion to T11 with an L1–L2 Smith-Petersen osteotomy in order to obtain maximal correction with the ACR. Finally, we performed T10–T12 vertebroplasties as part of our strategy for prevention of proximal junctional kyphosis. Both surgery stages were to be performed on the same day. Informed written consent was obtained from the patient, who wished to proceed. The key steps are demonstrated in the accompanying video (*Video 1*).

Highlight box

Surgical highlights

- This manuscript and accompanying video provide insights into anterior column alignment surgery for treating fixed spinal deformity or severe sagittal imbalance. The surgical technique for anterior column alignment is discussed, shedding light on established practices and their outcomes.

What is conventional and what is novel/modified?

- Surgical correction of fixed kyphotic deformity or severe sagittal imbalance traditionally involves three column osteotomies such as pedicle subtraction osteotomy which carry a high morbidity.
- Anterior column realignment is a minimally invasive alternative for restoring segmental lordosis.

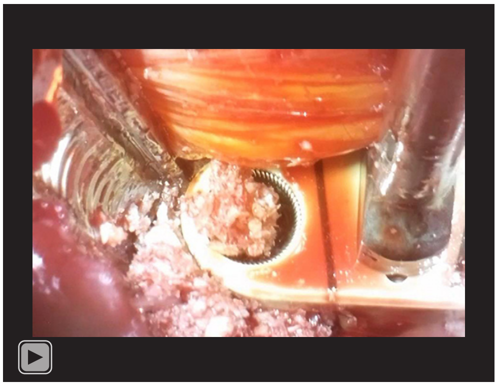
What is the implication, and what should change now?

- This anterior column realignment technique offers the potential for enhanced spinal alignment, improved biomechanics, and better long-term functional outcomes for patients. It is recommended that surgeons familiarize themselves with this innovative approach and consider its incorporation into current surgical practices.

Step-by-step description

All procedures performed in this study 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 article and accompanying video. A copy of the written consent is available for review by the editorial office of this journal.

The patient was brought to the operating room at a tertiary, academic hospital. Surgical personnel included the surgeon, the surgical fellow, charge nurse, scrub nurse, and anesthesiologist. A formal timeout was performed verifying the correct patient, procedure, and side. General anesthesia was induced and the patient was endotracheally intubated. For the first stage of the procedure, the patient was positioned in the lateral decubitus position with her left side up. Her arms were kept outstretched and padded on arm boards. An axillary roll was placed and her legs were appropriately padded. Her body was taped securely to the table, which was kept in a neutral position. Antero-posterior (AP) and lateral fluoroscopy were used to position the bed such that true AP and lateral images were obtained of the



Video 1 The key steps of anterior column realignment in a 56-year-old woman presenting with back pain in the setting of a flatback deformity and adjacent segment disease.

spine. A 4 cm transverse incision in line with the disc space was planned that gave access to the L1–L2 disc space. The patient was prepped and draped in the usual sterile fashion and local anesthetic was administered. The accompanying video to this manuscript shows stage 1.

The incision was made with a 10-blade scalpel and subcutaneous tissue was taken down with electrocautery. We exposed, dissected, and partially resected a rib that was in the surgical corridor. Bone was saved for use as morselized autograft later. The lung was identified and mobilized rostrally. The initial dilator and a Kirschner wire were introduced into the L1–L2 disc space around the "50-yard line" on the lateral X-ray. The initial dilator was circumferentially stimulated without elicitation of neuromonitoring signal. Increasing sized dilators were also placed and circumferentially stimulated. Then, an expandable retractor was placed. A Prass probe was used to stimulate within the operative field, again without any signal. The disc space was bipolar coagulated. It was incised with a long scalpel. A variety of instruments were used to perform an L1–L2 discectomy as well as to prepare the L1 and L2 endplates. These instruments included straight and angled Cobb elevators, straight and curved curettes, ring curettes, rasps, and box cutters. Then, gradually increasing trials were introduced into the disc space. Once we reached one of a snug fit, the ALL was carefully dissected and incised with a knife. During dissection of the ALL, care must be taken to avoid vascular injury to the aorta or vena cava, depending on side of approach. Both using a disc jack device as well as inserting increasingly large trials sequentially led to controlled, intentional disruption of the anterior longitudinal ligament, hence performing an anterior column release.

We then introduced hyperlordotic trials. Once we reached a trial of a snug fit and good appearance on fluoroscopy, a corresponding hyperlordotic 20-degree PEEK cage was packed with morselized autograft from the rib and allograft bone product. This cage was introduced into the L1–L2 disc space with excellent appearance on fluoroscopy. The cage had an integrated plate. We awled the screw hole into L1. We then placed a screw into L1 in order to firmly secure the cage.

Our attention then turned to closure. The wound was irrigated thoroughly, the retractor was removed, and the tissues were closed in layers with sutures, with care taken to repair the parietal pleura. This completed stage 1.

For stage 2 of the procedure, the patient was positioned prone on a Jackson table compatible with an intraoperative CT scanner. Care was taken to pad all pressure points. AP fluoroscopy was used to plan a midline incision spanning from T10 to the existing crosslink between L3 and L4. An incision was made with a 10-blade scalpel and further midline and subperiosteal dissection was performed with Bovie cauterization. We exposed the posterior elements from T10–L1 and the existing instrumentation at L2–L3. The crosslink was removed, and the screw caps in L2 and L3 were removed. A metal cutting bur was then used to divide the rods bilaterally below L3, and these rod fragments were removed. Inline connectors were placed into the existing rods. Then, the existing pedicle screws at bilateral L2 and left L3 were replaced with longer pedicle screws based on the patient's preoperative imaging. The right L3 pedicle screw impinged upon the inline connector, so this screw was not replaced.

We then instrumented from T11–L1. We used fenestrated screws at T11 and T12. We then performed an L1–L2 Smith-Peterson osteotomy. The pedicles of T10 were cannulated with Jamshidi needles. An intraoperative CT was then performed and demonstrated good placement of instrumentation. Approximately 4 mL of kyphoplasty cement was placed into T10 (2 mL on each side). We also placed no more than 2 mL of cement down each of the pedicle screws of T11 and T12. This completed the T10–T12 vertebroplasties, which was done to prevent proximal junctional kyphosis.

Rods were cut to size and bent to be appropriately lordotic in the lumbar spine. We compressed across the L1–L2 Smith-Petersen osteotomy. *In situ* bending was performed to reduce the thoracic portion of the rods into those pedicle screws. Final AP and lateral fluoroscopy confirmed appropriate placement of instrumentation. We then added an accessory rod on the left using offset connectors, one below the inline connector and the other between the T11 and T12 pedicle screws. This was designed to span the ACR site and the in-line rod connectors.

The wound was then copiously irrigated. Any existing posterior bone from T11–L3 was decorticated with a high-speed drill. In these decorticated areas, we laid a mixture of morselized autograft, morselized allograft, and bone morphogenetic protein to serve as the T11–L3 posterolateral arthrodesis. A drain was tunneled superiorly to the skin, and the wound was then closed in layers. The patient tolerated the procedure well. There were no complications. The total operative time was 8 h and estimated blood loss was 1.1 L. Of note, intraoperative neuromonitoring was used and there was no change in the baseline motor or somatosensory evoked potentials during the case.

Postoperative considerations and tasks

Postoperatively, the patient did well and was discharged on postoperative day four. At her 6-week postoperative visit, the patient stated that she was pain-free. She estimated her preoperative low back pain to be 100% improved, adding that it was the first time in 14 years where she had not been in pain. She remained neurologically intact on examination. X-rays obtained demonstrated a lumbar lordosis of 42 degrees, which matched her pelvic incidence of 46, and she had a pelvic tilt of 20 degrees, within normal limits.

Tips and pearls

Careful preoperative planning is essential to assess sagittal alignment accurately and determine the required correction. Adequate exposure and mobilization of anterior column structures are crucial for successful ACR surgery. Specialized instrumentation, such as distractors and hyperlordotic cages, can facilitate the realignment and fusion process. Incorporating posterior column stabilization techniques enhances construct stability.

Discussion

Spinopelvic disharmony contributes significantly to pain in patients with spinal deformities, and ACR when combined with a posterior release can enable manipulation of all three columns of the spine and allow for reconstruction of the spine and improvement of spinopelvic harmony. We performed an ALL release with placement of a hyperlordotic cage, with additional resection of both the inferior facet at L1 and superior facets at L2. A comprehensive realignment classification of combined ACR and posterior column osteotomies (PCO) has been developed to improve standardization amongst clinicians and researchers (5). The ACR/PCO modification ranges from grade A (with ALL release with hyperlordotic cage and intact posterior elements) to grade 6 complete removal of a vertebral body and both adjacent discs. A component of the ACR/PCO classification is the comprehensive anatomical spinal osteotomy classification developed for posterior osteotomies by Schwab *et al.*, and ranges from grade 1 to grade 6 based on increasing anatomic resection (6). According to this classification, our surgery is classified as a lateral grade 2 ACR with a Schwab modifier of 2, which indicates a complete facetectomy. A grade 2 ACR includes ALL release with placement of a hyperlordotic cage as well as resection of both superior and inferior facets, interspinous ligament, ligamentum flavum, lamina, and spinous process. In our case, with a grade 2 ACR we obtained 27 degrees of segmental lordosis across L1–L2 with a 20-degree cage. This is consistent with other studies, which have reported that with a 20-degree cage, correction of between 22–25 degrees can be obtained (3,7).

Important predictors for patient-reported and mechanical outcomes in ASD are corrected sagittal vertical axis (SVA), pelvic tilt (PT), and the mismatch between pelvic incidence and lumbar lordosis (PI-LL) (8,9). PI-LL mismatch correlates strongly with SVA, and good outcomes require balanced sagittal alignment (10). Roussouly *et al.* proposed the use of PI as a basis for determining lumbar morphology in the normative physiologic spine (11,12). Pesenti *et al.* subsequently showed that distal lumbar lordosis (DLL) remains relatively conserved, maintaining a value of approximately 35°, and that additional proximal lumbar lordosis (PLL) is "recruited" as PI increases (13). Based on this, an upper lumbar ACR may potentially be indicated in a patient with a Roussouly type 4 spine (those with a high pelvic incidence requiring more than 50% lordosis above L4) with a stiff focal kyphotic deformity at L1–L2. What remains unclear for other cases is the ideal distribution of LL as it relates to pelvic morphology in the corrected pathologic spine, and performing an upper lumbar ACR for spinal deformity should only be performed after careful consideration of spinal parameters.

The authors are of the opinion that patients with sagittal deformity and/or PI-LL mismatch benefit from increased lordosis and improved sagittal balance, regardless of where the apex of lordosis is located. About two-thirds of physiologic lumbar lordosis occurs between L4–S1, and there is concern that placing the lumbar apex in the upper lordotic levels can create a new mismatch with the lower kyphotic arc of the thoracic spine, which can lead to proximal junctional kyphosis and failure. However, the ideal shape of the fused spine remains unclear. There is evidence suggesting that Global Alignment and Proportion (GAP) scores and lumbar disability index are not associated with long-term outcomes (14). For instance, the GAP score is designed to predict risk for mechanical complications after ASD surgery and is based on global alignment parameters in relation to pelvic incidence, notably including the morphologic parameter lumbar distribution index (LDI) (15). Kwan *et al.* in an external validation study done by the Arbeitsgemeinschaft für Osteosynthesefragen (AO) Spine and Scoliosis Research Society, however, did not demonstrate increased risk of mechanical complications with higher GAP scores at 2 years (14). Im *et al.* concluded in a retrospective review of 228 consecutive cases of 8-segment T10–S1 posterior spinal fusion with pedicle subtraction osteotomy or multi-level Smith-Petersen osteotomy that post-operative PI-LL was the sole parameter significantly associated with achieving post-operative "balance" (SVA <5 cm) at a mean follow-up of 45.3 months (16). Specifically, they did not find an association between lumbar morphologic parameters (PLL, DLL, and LDI) and sagittal alignment. Another study by the International Spine Study Group found that non-mechanical revision surgery at 1-year was associated with lower osteotomy level (specifically L4 *vs.* L3) (17). Finally, the authors of this manuscript have a forthcoming series of 20 upper lumbar ACR patients, of whom none developed proximal junctional failure (manuscript in preparation). Overall, these works support the notion that achieving overall spinopelvic balance may be the most important factor in future risk for mechanical failure, as opposed to corrected lumbar lordosis morphology.

Conclusions

This case demonstrates the clinical value of minimally-invasive ACR surgery for treatment of spinal deformity in which there is compensatory pelvic retroversion. ACR can also correct spinopelvic parameters to a similar degree as traditional posterior approaches (18). ACR is an emerging minimally invasive surgery technique for ASD surgery and as ACR becomes more widely adopted, larger studies will be needed to confirm its efficacy and safety for ASD surgery.

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Footnote

Reporting Checklist: The authors have completed the SUPER reporting checklist. Available at https://jss.amegroups.com/article/view/10.21037/jss-23-45/rc

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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 this study 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 article and accompanying video. A copy of the written consent is available for review by the editorial office of this journal.

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