Original Article

Anterior column realignment (ACR) for focal kyphotic spinal deformity using an anterior to psoas approach and anterior longitudinal ligament release

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Background: The anterior-to-psoas (ATP) approach to the lumbar spine has been proposed as an alternative to the transpsoas approach for approaching the disc space without dissecting through the psoas muscle, thus decreasing the risk of injury to the lumbar plexus. There are no prior studies that evaluates the clinical application of anterior longitudinal ligament (ALL) release and anterior column realignment (ACR) using the ATP approach. The objective of this study was to describe and evaluate the safety of ACR using an ATP approach with release of both the ALL and bilateral annulus for correction of a focal kyphotic lumbar deformity.

Methods: A retrospective analysis of fourteen consecutive patients at a single institution between January 2017 and December 2019 of patients undergoing ACR using an ATP approach for lumbar flatback syndrome with focal kyphotic lumbar deformity by a single surgeon was performed. Primary outcome measures were pre- and postoperative radiographic parameters. Secondary outcome measures were perioperative adverse events (AEs), 30-day readmissions/reoperations, discharge disposition, post-operative length of stay (LOS), and radiographic complications.

Results: Fourteen consecutive patients (mean age 67.0±3.9 years, 8 males, 6 females) with 15 total ACR levels were included in the study. A grade 1 posterior column osteotomy (PCO) with posterior instrumentation was performed at all ACR levels. L2–L3 ACR was performed in nine patients, L3–L4 in four patients, and L4–L5 in two patients. Mean preoperative disk lordotic angle at the ACR level was 5.4°±5.9° of kyphosis. Mean increase in postoperative disk lordotic angle was 24.0°±8.5° at a mean follow-up of 34.0±23.4 months.

Conclusions: ACR can be performed with a complete ALL release under direct visualization using the ATP approach. This technique can be a safe and effective method for achieving substantial correction of a focal kyphotic deformity within the lumbar spine.

Keywords: Anterior-to-psoas (ATP); anterior column realignment (ACR); anterior longitudinal ligament release (ALL release); spinal deformity

Submitted Jun 18, 2023. Accepted for publication Sep 08, 2023. Published online Oct 09, 2023.
doi: 10.21037/jss-23-84
View this article at: https://dx.doi.org/10.21037/jss-23-84

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Introduction

Sagittal balance is essential for the success of adult spinal deformity surgery (ASD), and its restoration has been linked to improved health-related quality of life outcomes (1). However, traditional methods for correcting kyphotic deformities, such as three-column osteotomy and vertebrectomy, are associated with significant morbidity, including prolonged operative times, neurological complications, high rates of blood loss, perioperative complications and increased likelihood of revision surgery (2,3).

Recently, anterior column realignment (ACR) with release of the anterior longitudinal ligament (ALL) has been introduced as a powerful alternative to achieve adequate restoration of sagittal alignment (4). The lateral transpsoas approach has been mainly described in the literature for this procedure, but it has limitations such as the need for dissection through the psoas muscle, risk of injury to the lumbar plexus, and inadequate visualization of the great vessels during ALL release (4-6).

The anterior-to-psoas (ATP) approach to the lumbar spine has been proposed as an alternative to the transpsoas approach for approaching the disc space without dissecting through the psoas muscle, thus decreasing the risk of injury to the lumbar plexus (7). However, the ATP approach has its limitations including risks of injury to the sympathetic nerves and the great vessels (7). Nevertheless, when performing an ACR, the ATP approach confers the benefit of direct visualization and protection of the great vessels during the ALL release.

Although a recent study demonstrated the radioanatomic feasibility of performing a complete ALL release and ACR using the ATP approach at the L1–L5 levels, to our knowledge, there are no prior studies that evaluates the clinical application of this technique (8). Thus, the objective of this study was to describe and evaluate the safety of ACR using an ATP approach with complete release of ALL and annulus for correction of focal kyphotic lumbar deformity. We hypothesized that ACR can be performed with a complete ALL release under direct visualization using the ATP approach and can be a safe and effective method for achieving substantial correction of a focal kyphotic deformity within the lumbar spine. We present this article in accordance with the STROBE reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-23-84/rc).

Highlight box

Key findings

- Anterior column realignment (ACR) can be performed with a complete anterior longitudinal ligament (ALL) release under direct visualization using the anterior-to-psoas (ATP) approach.

What is known and what is new?

- The ATP approach to the lumbar spine is an alternative to the transpsoas approach to the disc space without dissecting through the psoas muscle, thus decreasing risk of injury to the lumbar plexus.
- ACR can be performed with a complete ALL release under direct visualization using the ATP approach and can be a safe and effective method for achieving substantial correction of a focal kyphotic deformity within the lumbar spine.

What is the implication, and what should change now?

- ALL release and ACR using an ATP approach can be a safe and effective method of achieving substantial correction of a focal kyphotic deformity within the lumbar spine.
- This technique is an essential addition to the currently described techniques of obtaining deformity correction in the literature.

Methods

Patient selection

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the institutional review board of Houston Methodist Hospital (No. PRO00032736) and individual consent for this retrospective analysis was waived.

A retrospective analysis of fourteen consecutive patients at a single institution between January 2017 and December 2019 of patients undergoing ACR using an ATP approach for lumbar flatback syndrome and a focal kyphotic deformity by a single surgeon was performed. Primary outcome measures were pre- and postoperative radiographic parameters. Secondary outcome measures were perioperative adverse events (AEs), 30-day readmissions/reoperations, discharge disposition, post-operative length of stay (LOS), and radiographic complications.

Surgical technique

Preoperative planning

During preoperative planning for adult spinal deformity surgery, full-length standing, cross-table lateral spine flexion, and hyperextension radiographs was obtained to evaluate the flexibility of the apical intervertebral disk. In addition to radiographic imaging, a computed tomography

(CT) myelogram or magnetic resonance imaging (MRI) was used to evaluate the feasibility of performing an ACR using the ATP approach as previously described.

ACR using ATP approach

All surgical procedures were performed by a single fellowship-trained orthopedic spine surgeon. Each patient was placed in a right lateral decubitus position on a Jackson spinal surgery table under general anesthesia. A pre-incisional localization was completed with anteroposterior (AP) and lateral fluoroscopic views. A retroperitoneal approach was carried out with a 3–4 cm oblique incision centered over the target disc. The ATP corridor was identified under direct visualization. Careful mobilization and anterior retraction of the great vessels and posterior retraction of the psoas muscle was performed. Steinmann pins were placed within the vertebral bodies to maintain complete exposure of the target disc space. The disc preparation and bilateral annulus resection was completed using a combination of a 15-blade scalpel, Cobb elevators, osteotomes, and pituitaries. The endplates were prepared for fusion using rasps and sequential interbody trials with particular care taken for bony endplate preservation. The ALL was released in its entirety using a 15-blade scalpel or reverse angle curette with the great vessels gently retracted under direct visualization. An appropriately sized lordotic cage packed with cancellous allograft and recombinant human bone morphogenetic protein-2 (RhBMP-2) was placed while protecting the anterior structures. Supplemental anterior instrumentation was used for one patient (Patient #8) who underwent an L3 partial corpectomy after obtaining a 42.9-degree correction at L2–L3. Supplemental anterior fixation using a flanged cage was used for one patient (Patient #10) after obtaining a 20.0-degree correction at L4–L5.

Posterior procedure

Upon completion of the anterior procedure, the posterior procedure was completed in a staged fashion at a later day with the exception of one patient (Patient #5). An additional grade 1 posterior column osteotomy (PCO) was performed at the level of the ACR as described by Schwab *et al.* (9). Thorough decortication of the fusion bed in preparation for a posterolateral fusion was completed and pedicle screw instrumentation was placed.

Thromboembolic protocol

Perioperative tranexamic acid was administered at a loading dose of 30 mg/kg followed by a 3 mg/kg/h infusion. Early mobilization, compression stockings and pneumatic sequential compression devices were used for deep vein thrombosis (DVT) prophylaxis. Prophylactic anticoagulation was not routinely used; instead, routine postoperative lower extremity duplex ultrasound was performed on all patients prior to discharge and at the first follow up visit. Patients received therapeutic anticoagulation if a DVT is found.

Radiographic evaluation

The disk lordotic angle, anterior disk height, and posterior disk height were measured on standing lateral lumbar radiographs for each operated disk preoperatively, postoperatively, and at final follow-up. The disk lordotic angle was calculated as the angle between the caudal endplate of the cranial vertebra and the cranial endplate of the caudal vertebra as previously described (3). On the standing scoliosis radiographs, sagittal parameters including sagittal vertical axis (SVA), pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT), and lumbar lordosis (LL) were measured before surgery, immediately after surgery, and at the final follow-up. Fusion grade was evaluated using a previously described method (10). A grade 1 fusion was defined as fusion with remodeling and trabeculae present, grade 2 for intact graft but not fully remodeled and incorporated with no lucency present, grade 3 for intact graft with lucency surrounding the graft, and grade 4 for absence of fusion with collapse or resorption of the graft (10). Grades 1 and 2 were considered successful fusion within this study. Cage subsidence was defined as a cage sinking into an adjacent vertebral body by >2 mm, based on comparisons with previous radiographs, and was evaluated using postoperative and serial follow-up radiographs. Proximal junctional kyphosis (PJK) was defined as a proximal junctional angle (PJA) magnitude of ≤–28° or a change of ≤–22° measured between the upper instrumented vertebrae –1 (UIV–1) and UIV+2 as recently re-defined by Lovecchio *et al.* (11). Proximal junctional failure (PJF) was defined as symptomatic PJK requiring revision surgery. All radiological measurements were carried out by a single spinal surgeon who was not involved in patient care.

Statistical analysis

Data analysis was performed using SPSS statistical software (Version 25.0; SPSS, Inc., Chicago, IL, USA). Descriptive

statistics were presented using mean ± standard deviation (SD) for continuous variables and frequencies (%) for categorical variables. Two-tailed student *t*-test was used to analyze continuous data and the Chi-Square or Fisher's exact test was used to analyze categorical data. The Mann-Whitney *U* test was utilized for continuous variables with non-normal distribution. A P value <0.05 was considered statistically significant.

Results

Patient demographics

Fourteen consecutive patients (mean age 67.0±3.9 years, 8 males, 6 females, mean follow-up 34.0±23.4 months) with 15 total ACR levels were included in the study (*Table 1*).

All patients had a history of flatback syndrome and a focal kyphotic deformity within the lumbar spine. A grade 1 PCO with posterior instrumentation was performed at all ACR levels. L2–L3 ACR was performed in nine patients, L3–L4 in four patients, and L4–L5 in two patients. Mean estimated blood loss (EBL) for the anterior procedure was 356±371 mL. Mean EBL for the posterior procedure was 761±627 mL. Mean total EBL was 1,097±992 mL.

Radiographic outcomes

Mean preoperative lumbar lordosis was 22.7°±18.4° (*Table 2*). Mean lumbar lordosis immediately after surgery and at final follow-up was 50.6°±13.4° (P<0.001) and 48.7°±14.8° (P<0.001), respectively. Mean increase in postoperative lumbar lordosis was 26.0°±12.2° at final follow-up. Mean decrease in PT and increase in SS was 5.5±6.1° and 7.2°±6.3°, respectively at final follow-up.

Mean preoperative disk lordotic angle at the ACR level was 5.4°±5.9° of kyphosis (*Table 3*). Mean disk lordotic angle immediately after surgery and at final follow-up was 20.6°±6.3° (P<0.001) and 18.7°±5.3° (P<0.001) of lordosis, respectively. Mean increase in postoperative disk lordotic angle was 24.0°±8.5° at final follow-up. Mean preoperative anterior disc height at the ACR level was 1.9±1.7 mm with a mean increase of 14.4±4.3 mm at final follow-up. Mean preoperative posterior disc height was 4.3±2.3 mm with a mean increase of 0.8±2.3 mm at final follow-up.

All patients had a successful grade 1 or grade 2 fusion at the ACR level at final follow-up (*Table 4*). Thirteen patients (92.9%) had a grade 1 fusion and one patient (7.1%) had a grade 2 fusion at 4-month final follow-up. One patient (7.1%) had post-operative subsidence of the cage. This same patient experienced PJK and PJF requiring revision extension at a follow-up of 56 months. No other patients experienced PJK or PJF using the most recently described definition (11). There were no cases of pseudarthrosis or instrumentation failure.

Functional outcomes

Thirteen patients (92.9%) reported improvement in pain and mobility at final mean follow-up of 34.0±23.4 months. There were no cases of new lower extremity paresis, paresthesia, or increased lower extremity pain post-operatively including thigh pain or pain with hip flexion. One patient (7.1%) experienced increasing back pain starting 51 months post-operatively and underwent revision extension at a follow-up of 56 months due to PJK and PJF as described previously.

AEs

Nine patients (63.4%) experienced one or more perioperative AEs (*Table 5*). The mean LOS was 9.1±2.9 days. There was one case of 30-day re-admission due to the development of a small pulmonary embolus, which was successfully treated with therapeutic anticoagulation. There were no cases of 30-day reoperations. Seven patients were discharged home, six patients were discharged to a rehabilitation facility, and one patient to a skilled nursing facility. Post-operative acute kidney injury (AKI) was the most common AE with four cases followed by, three cases of anemia requiring transfusion, two DVTs, and one case each of urinary tract infection, pulmonary embolism, pneumonia, and ileus requiring temporary nasogastric tube (NGT) and bowel rest.

Discussion

This study aimed to describe and assess the safety of ACR using an ATP approach with complete release of the ALL and annulus for correcting a focal kyphotic lumbar deformity in patients with lumbar flatback syndrome. This technique allowed a mean increase of disk lordotic angle of 24.0°±8.5° at a final follow-up of 34.0±23.4 months without major intraoperative complications or 30-day reoperations. We reported a 100% successful fusion rate and one case of post-operative subsidence and PJK requiring revision extension of the fusion construct. Overall, these results were similar to a recent study reporting a modified ACR

Table 1 Patient demographics

Patients No.	ACR level(s)	Age (y)	Sex	F/U (mo)	Previous spine surgery	Diagnosis	Cage lordotic angle (deg)	ASI	Additional interbodies	Osteotomy grade at ACR level	Additional osteotomies	PSIF levels	Anterior EBL (mL)	Posterior EBL (mL)	Total EBL (mL)
1	L2–L3	63	M	36	L1–L3 PSIF/TLIF, L4–S1 ALIF	Pseudarthrosis, FBS, FKD	15	No	No	Grade 1	No	T11–S1	100	1,000	1,100
2	L2–L3	68	F	4	L3–S1 PSIF, L3–L4 TLIF, L5–S1 TLIF	ASD, FBS, FKD	15	No	L1–L2 LLIF	Grade 1	L1–2 grade 2	L1–S1	200	300	500
3	L3–L4	73	M	65	L4–L5 PSIF/TLIF	ASD, FBS, FKD	15	No	L5–S1 ALIF	Grade 1	No	L3–L5	10	250	260
4	L4–L5	67	F	15	L5–S1 PSIF/TLIF	ASD, FBS, grade 2 DLS	15	No	No	Grade 1	L3–L4 grade 2	L3–S1	50	350	400
5	L3–L4	66	F	68	L3–S1 PSIF	FBS, FKD	15	No	No	Grade 1	No	L2–L5	1,100		1,100
6	L3–L4	68	M	25	N/A	FBS, FKD, grade 2 DLS	20	No	L4–L5 ALIF	Grade 1	L4–L5 grade 2	L3–L5	50	200	250
7	L2–L3	65	F	66	L3–S1 ALIF L3–S1 PSIF	ASD, FBS, FKD	15	No	L5–S1 ALIF	Grade 1	None	T3-pelvis	400	1,300	1,700
8	L2–L3	66	F	12	L1 kyphoplasty, L2-3 TLIF, L4–S1 PSIF, L5–S1 ALIF	ASD, FBS, FKD	Titanium mesh cage cut in lordosis	Yes	L5–S1 ALIF	Grade 1	L1–L2, L3–L4, L5–S1 grade 2	T10-pelvis	300	200	500
9	L2–L3	67	M	36	L4–L5 PSIF/TLIF	ASD, FBS, FKD	15	No	L5–S1 ALIF	Grade 1	L1-2, L2-3, L5–S1 grade 2	T11-pelvis	1,000	1,100	2,100
10	L4–L5	68	M	10	T11–S1 PSIF, L3–L4 LLIF, L4–L5 TLIF, L5–S1 ALIF	FBS, FKD	20	Yes	T12–L1, L1–L2 LLIF	Grade 1	T12–L1, L1–L2 grade 2	T11-pelvis	1,000	750	1750
11	L2–L3, L3–L4	71	M	4	L4–S1 PSIF	ASD, FBS, FKD	15, 15	No	No	Grade 1	L1–L2 grade 2	T10–S1	350	700	1,050
12	L2–L3	61	M	56	L3–S1 PSIF, L4–S1 ALIF	ASD, FBS, FKD	15	No	L1–L2 LLIF	Grade 1	L1–L2 grade 2	T9–S1	150	600	750
13	L2–L3	61	M	48	L4–S1 PSIF, L5–S1 ALIF	ASD, FBS, FKD	15	No	L1–L2 LLIF	Grade 1	L1–L2 grade 2	T5–S1	1,000	2,500	3,500
14	L2–L3	74	F	31	L3–S1 PSIF	ASD, FBS, FKD	15	No	L1–L2 LLIF	Grade 1	L1–L2 grade 2	T9-pelvis	100	300	400

ACR, anterior column realignment; F/U, follow-up; ASI, anterior spinal instrumentation; PSIF, posterior spinal instrumented fusion; EBL, estimated blood loss; M, male; TLIF, transforaminal lumbar interbody fusion; ALIF, anterior lumbar interbody fusion; FBS, flatback syndrome; FKD, focal kyphotic deformity; F, female; ASD, adjacent segment disease; LLIF, lateral lumbar interbody fusion; DLS, degenerative lumbar spondylolisthesis.

Table 2 Sagittal parameters

Patients No.	ACR level(s)	Pelvic tilt (°)				Sacral slope (°)				Pelvic incidence (°)				C7 SVA (mm)				Lumbar lordosis (°)			
		Preop	Postop	Final	Final changes	Preop	Postop	Final	Final changes	Preop	Postop	Final	Final changes	Preop	Postop	Final	Final changes	Preop	Postop	Final	Final changes
1	L2–L3	29.8	30.3	35.4	5.6	29.5	28.4	30.7	1.2	59.3	58.7	66.1	6.8	93.8	64.3	65.5	−28.3	28.8	58.1	56.4	27.6
2	L2–L3	32.6	24.5	23.5	−9.1	34.1	42.6	43.3	9.2	66.7	67.1	66.8	0.1	90.9	NA	NA	NA	21.2	52.1	52.0	30.8
3	L3–L4	20.8	14.8	14.8	−6.0	31.8	42.4	42.4	10.6	52.6	57.2	57.2	4.6	31.2	NA	91.7	60.5	39.4	57.9	57.9	18.5
4	L4–L5	38.2	28.6	30.2	−8.0	36.8	45.5	44.1	7.3	75.0	74.1	74.3	−0.7	49.6	25.2	26.4	−23.2	43.5	61.8	60.6	17.1
5	L3–L4	41.9	37.6	38.5	−3.4	43.9	48.3	47.6	3.7	85.8	85.9	86.1	0.3	35.6	27.5	20.2	−15.4	45.9	73.1	72.7	26.8
6	L3–L4	42.5	33.5	34.3	−8.2	25.8	35.4	34.1	8.3	68.3	68.9	68.4	0.1	97.3	53.7	62.6	−34.7	42.5	60.3	59.5	17.0
7	L2–L3	40.6	38.9	38.4	−2.2	16.6	19.9	18.9	2.3	57.2	58.8	57.3	0.1	57.8	13.1	65.9	8.1	14.4	38.6	32.3	17.9
8	L2–L3	50.2	30.6	32.1	−18.1	5.2	26.2	27.2	22.0	55.4	56.8	59.3	3.9	112.2	8.0	16.0	−96.2	−7.7	46.6	45.0	52.7
9	L2–L3	35.8	28.0	29.0	−6.8	30.7	45.0	45.0	14.3	66.5	73.0	74.0	7.5	130.0	4.7	4.7	−125.3	37.0	65.0	65.0	28.0
10	L4–L5	22.5	23.5	22.9	0.4	22.6	21.6	23.6	1.0	45.1	45.1	46.5	1.4	116.5	96.9	100.2	−16.3	28.8	40.1	39.6	10.8
11	L2–L3, L3–L4	37.2	23.4	23.4	−13.8	17.3	30.7	30.7	13.4	54.5	54.1	54.1	−0.4	220.6	119.6	119.6	−101.0	−2.3	48.1	48.1	50.4
12	L2–L3	20.6	20.9	21.9	1.3	13.1	13.9	12.0	−1.1	33.7	34.8	33.9	0.2	72.1	41.6	57.7	−14.4	5.4	27.2	22.3	16.9
13	L2–L3	38.7	33.3	34.2	−4.5	21.2	26.3	25.4	4.2	59.9	59.6	59.6	−0.3	219.8	152.3	141.3	−78.5	−1.2	29.1	26.4	27.6
14	L2–L3	39.1	26.9	34.5	−4.6	17.5	30	22.4	4.9	56.6	56.9	56.9	0.3	203.1	78.7	52.4	−150.7	21.8	49.8	44.2	22.4
Mean		35.0	28.2	29.5	−5.5	24.7	32.6	32.0	7.2	59.8	60.8	61.5	1.7	109.3	60.7	66.7	−47.3	22.7	50.6	48.7	26.0
SD		8.8	6.6	7.1	6.1	10.4	10.8	11.1	6.3	12.7	12.7	12.8	2.8	64.3	44.2	37.8	59.1	18.4	13.4	14.8	12.2
P (*vs.* preop)		–	<0.001*	0.004*	–	–	<0.001*	<0.001*	–	–	0.087	0.039*	–	–	<0.001*	0.013*	–	–	<0.001*	<0.001*	–

*, statistically significant values. ACR, anterior column realignment; SVA, sagittal vertical axis; NA, not acquired; SD, standard deviation.

Table 3 Intradiscal radiographic parameters

Patients No.	ACR level	Disc lordotic angle (°)				Anterior disc height (mm)				Posterior disc height (mm)			
		Preop	Postop	Final	Final changes	Preop	Postop	Final	Final changes	Preop	Postop	Final	Final changes
1	L2–L3	–6.0	15.2	14.8	20.8	3.3	14.1	13.8	10.5	7.1	8.6	8.2	1.1
2	L2–L3	–7.5	28.2	25.6	33.1	0.0	14.8	14.1	14.1	3.4	5.1	5.1	1.7
3	L3–L4	–0.2	14.2	14.2	14.4	3.1	12.5	12.5	9.4	3.8	3.9	3.9	0.1
4	L4–L5	–0.9	32.7	27.6	28.5	1.2	22.5	22.4	21.2	0.0	5.9	5.6	5.6
5	L3–L4	–1.1	16.2	16.5	17.6	3.7	13.2	13.2	9.5	4.6	5.2	5.2	0.6
6	L3–L4	–1.9	21.6	19.4	21.3	0.9	14.9	14.6	13.7	2.1	3.8	3.8	1.7
7	L2–L3	–0.5	18.5	11.5	12.0	2.0	16.0	14.0	12.0	5.0	7.9	7.7	2.7
8	L2–L3	–11.5	31.4	27.1	38.6	0.0	25.6	24.8	24.8	6.9	6.8	7.2	0.3
9	L2–L3	–0.5	27.0	26.0	26.5	3.5	19.5	19.5	16.0	1.1	4.1	4.1	3.0
10	L4–L5	–0.1	19.9	15.8	15.9	5.2	17.3	16.8	11.6	5.6	6.9	6.7	1.1
11	L2–L3	–11.1	18.2	18.2	29.3	0.0	17.2	17.2	17.2	4.2	4.3	4.3	0.1
	L3–L4	–19.5	19.4	19.4	38.9	0.0	14.4	14.4	14.4	8.5	3.5	3.5	–5.0
12	L2–L3	–5.2	14.5	13.5	18.7	3.4	15.9	15.3	11.9	4.6	4.6	4.4	–0.2
13	L2–L3	–12.3	15.9	15.6	27.9	0.0	17.6	17.1	17.1	4.8	3.9	3.9	–0.9
14	L2–L3	–1.9	15.6	15.3	17.2	1.7	14.9	14.2	12.5	2.6	3.4	3.2	0.6
Mean		–5.4	20.6	18.7	24.0	1.9	16.7	16.3	14.4	4.3	5.2	5.1	0.8
SD		5.9	6.3	5.3	8.5	1.7	3.5	3.5	4.3	2.3	1.7	1.6	2.3
P (*vs.* Preop)		–	<0.001*	<0.001*	–	–	<0.001*	<0.001*	–	–	0.155	0.177	–

*, statistically significant values. ACR, anterior column realignment; SD, standard deviation.

Table 4 Radiographic complications

Patients No.	Subsidence	Fusion	UIV-1/UIV+2 PJA	PJA change from Preop	PJK	PJF
1	No	Grade 1	–21.3	–18.8	No	No
2	No	Grade 1	14.5	5.6	No	No
3	No	Grade 1	12.4	–5.1	No	No
4	No	Grade 1	28.7	–4.7	No	No
5	No	Grade 1	23.9	1.7	No	No
6	No	Grade 1	38.2	12.2	No	No
7	No	Grade 1	–11.6	–4.5	No	No
8	No	Grade 1	–17.9	–7.7	No	No
9	No	Grade 1	–11.8	–7.5	No	No
10	No	Grade 1	–16.1	–2.2	No	No
11	No	Grade 2	–22.6	–17.5	No	No
12	Yes	Grade 1	–32.7	–22.5	Yes	Yes
13	No	Grade 1	–25.5	–18.2	No	No
14	No	Grade 1	–18.1	–11.0	No	No

UIV, upper instrumented vertebrae; PJA, proximal junctional angle; PJK, proximal junctional kyphosis; PJF, proximal junctional failure.

Table 5 Perioperative adverse events and disposition

Patients No.	LOS (days)	30-day readmission	30-day reoperation	Disposition	Perioperative AE
1	7	No	No	Home	None
2	5	No	No	Home	AKI, anemia requiring transfusion
3	6	No	No	Home	None
4	7	No	No	SNF	DVT, AKI, anemia requiring transfusion
5	11	No	No	Home	None
6	11	No	No	Home	DVT
7	12	No	No	Rehab	None
8	11	No	No	Rehab	None
9	8	No	No	Home	Ileus requiring NGT/bowel rest
10	10	No	No	Rehab	Pneumonia
11	8	No	No	Home	UTI
12	7	No	No	Rehab	AKI
13	9	Yes, PE	No	Rehab	AKI, PE
14	16	No	No	Rehab	Anemia requiring transfusion

LOS, length of stay; AE, adverse event; AKI, acute kidney injury; SNF, skilled nursing facility; DVT, deep vein thrombosis; UTI, urinary tract infection; NGT, nasogastric tube; PE, pulmonary embolism.

technique using the ATP approach with a partial release of the ALL (12). Using a partial ALL release, Jeon *et al.* demonstrated an overall increase in disk lordotic angle of 15.8°±6.7° at a final follow-up of 42.6±14.5 months when combining with a grade 2 PCO (12). The same authors were able to achieve an overall increase in disk lordotic angle of 17.9°±6.2° when combining the modified ACR with a pedicle subtraction osteotomy (PSO). Our study demonstrates that by performing a complete release of the ALL combined with a grade 1 PCO, a larger degree of correction was possible.

Although an ACR is a powerful tool for achieving sagittal deformity correction, it is critical to appreciate spinal deformity principles prior to its use as prior studies have shown the importance of maintaining a majority of the lumbar lordosis at L4–L5 and L5–S1 (13-15). Patients presenting with flatback syndrome and minimal L4–S1 lordosis should avoid relying solely on an upper lumbar spine ACR to prevent complications at the proximal junction. In our patient cohort, 85.7% underwent ACR at either L2–L3 or L3–L4, but this procedure was strictly indicated for those with a rigid focal kyphotic deformity. Furthermore, these upper lumbar ACRs were supplemented with lower lumbar ALIFs when indicated (*Figure 1*, *Table 1*). The mean preoperative disk angle in the current study was 5.4°±5.9° of kyphosis. This is in comparison to Jeon *et al.*'s patient cohort with a mean preoperative disk lordotic angle of 0.4°±5.9° of lordosis who underwent a modified ACR with a grade 2 PCO (12). Thus, a modified ACR with partial release of the ALL is likely more appropriate for this patient cohort as performing a complete ALL release and achieving a larger lordosis correction may have led to an overcorrection in these deformities.

In all presented cases, the surgeon was able to completely visualize the ALL with gentle retraction of the great vessels prior to performing the ALL release. Therefore, in comparison with the original ACR technique using a transpsoas approach, the authors believe that performing an ACR using the ATP approach may be a safer technique when radioanatomically feasible. A prior study by Hirase *et al.* described the radioanatomic feasibility of performing an ACR using an ATP approach at L1–L5 and found that performing this technique was considered high risk (high-rising psoas or no measurable space between the ALL and the great vessels) in 13.0% of patients at the L2–L3 level, 40.7% at the L3–L4 level, and 89.0% at the L4–L5 level (8). The majority of the patients within our cohort underwent an ACR using an ATP approach were at the L2–L3 or

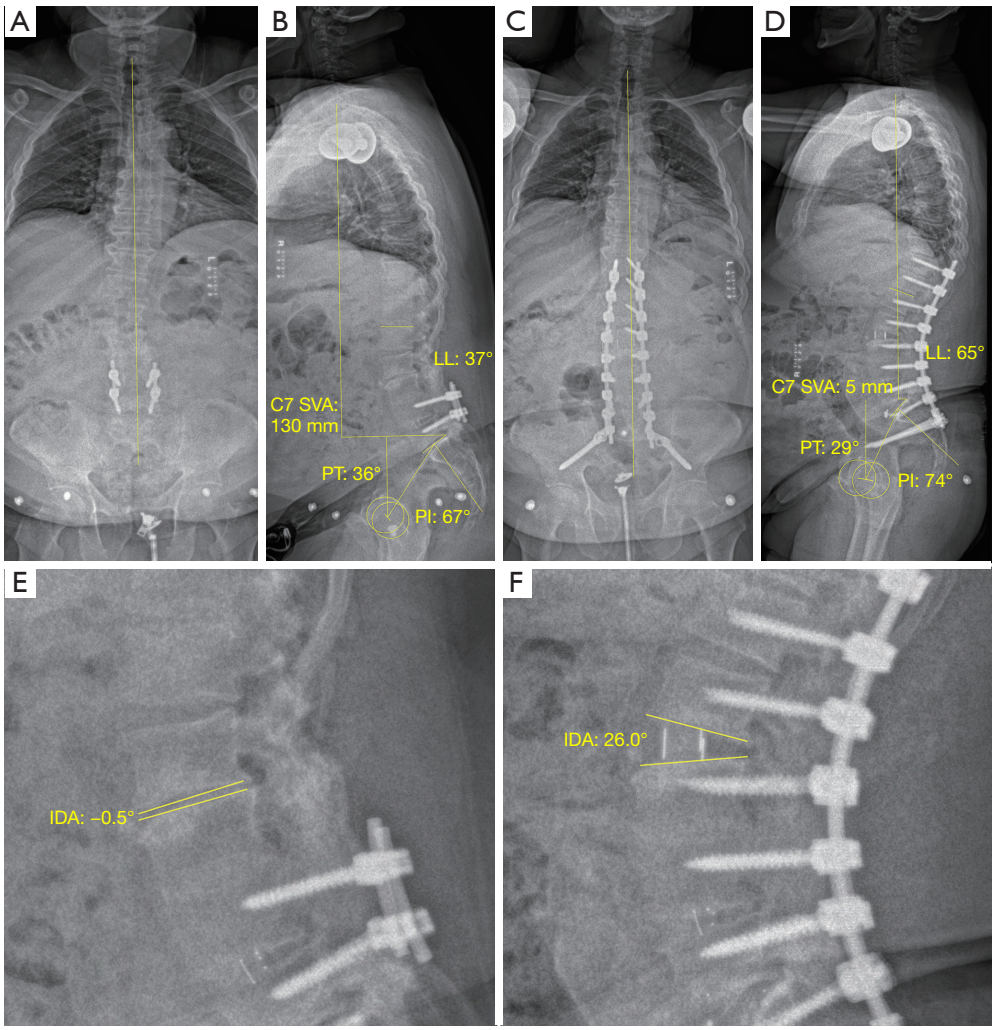

Figure 1 A 67-year-old male (case #9) with a prior L4–L5 TLIF who presented with severe sagittal imbalance due to flatback syndrome, adjacent segment disease, and an L2–L3 focal kyphotic deformity. A two-staged L2–L3 ACR, L5–S1 ALIF, grade 2 PCOs at L1–L2, L2–L3, L5–S1, and T11-pelvis PSIF was performed. (A,B) preoperative PA and lateral standing radiographs demonstrating a positive sagittal imbalance with a C7 SVA of 130 mm, LL of 37°, PI of 67°, and PT of 36°; (C,D) postoperative radiographs at 36-month follow-up demonstrating a C7 CVA of 5 mm, LL of 65°, PI of 74°, and PT of 29°. (E) Preoperative L2–L3 disk lordotic angle with 0.5° of kyphosis. (F) Postoperative L2–L3 disk lordotic angle of 26.0° of lordosis. SVA, sagittal vertical axis; LL, lumbar lordosis; PI, pelvic incidence; PT, pelvic tilt; IDA, intradiscal angle; TLIF, transforaminal lumbar interbody fusion; ACR, anterior column realignment; ALIF, anterior lumbar interbody fusion; PCO, posterior column osteotomy; PSIF, posterior spinal instrumented fusion; PA, posteroanterior.

L3–L4 level, largely due to the location of the focal kyphotic deformity and radioanatomic feasibility as presented by Hirase *et al.* (8).

Traditionally, a PJK was defined as a kyphotic change in the PJA of at least 10°. However, this definition was found by multiple studies to lack correlation with clinical outcomes (16-19). Lovecchio *et al.* recently proposed a new definition of PJK as a magnitude of ≤–28° or a change of ≤–22° measured between UIV–1 and UIV+2 and found that these cut-off values best predict the need revision surgery for PJK (11). One patient within our patient cohort met these criteria, which was also the same patient that required a revision extension of the fusion construct due to PJK/PJF. Our 100% fusion rate and 7.1% cage subsidence rates were also similar to the modified ACR using an ATP approach as presented by Jeon *et al.* who reported a 94.6% and 8.9%

fusion and subsidence rates, respectively (12).

Our study demonstrated a favorable safety profile, with no intraoperative major complications or 30-day reoperations. However, we found a high rate of perioperative medical AEs with nine patients (63.4%) experiencing one or more perioperative AEs (*Table 5*). The likely reason for these AEs is multifactorial. First, 13 of our 14 included patients were revision surgeries which have been shown to be associated with higher rates of perioperative AEs (20,21). All 13 of these patients were included within our sarcopenic cohort in our prior study that reported the association of sarcopenia with perioperative AEs after complex revision thoracolumbar spine surgeries (22). This study found that sarcopenic patients had a 75.5% rate of AEs compared to 27.7% in the non-sarcopenic group (22). Unfortunately, these patients with a prior lumbar fusion presenting with severe sagittal imbalance and flatback syndrome are largely disabled, immobile, and sarcopenic. Thus, particularly for this patient population, it is critical to offer adequate preoperative counseling regarding postoperative expectations in terms of preparing for AEs and the appropriate methods to treat each AE.

Our study has several limitations that should be acknowledged. Firstly, the retrospective, non-randomized nature of our investigation means that the accuracy of the data is dependent on the accuracy of the medical records and may also be prone to selection bias. However, our indications for this surgical technique were standardized to minimize selection bias. Additionally, our study only involved data from a single surgeon at a single institution, which may not be generalizable to other surgeons or centers that employ different surgical techniques or management strategies. Furthermore, our study had a relatively small sample size, which may have resulted in insufficient statistical power to identify certain associations. Finally, our institution did not utilize patient-reported outcome scores, which did not allow an objective measurement of post-operative functional outcomes. However, all outcomes were described in terms of subjective improvement in pain and mobility post-operatively at final follow-up and objective neurologic examination data was obtained and documented.

Despite these limitations, our study represents the most comprehensive investigation to date of the safety of ACR using an ATP approach with release of ALL and bilateral annulus for correction of a focal kyphotic lumbar deformity. To our knowledge, this is the largest study of its kind, and we believe that it provides valuable insights into the effectiveness and safety of this surgical technique. However, it is important to note that additional studies are needed to confirm the external validity of our findings before they can be applied in clinical practice. By addressing the limitations of our study and building upon its findings, future investigations can help to further elucidate the potential benefits and risks of ACR using an ATP approach with release of ALL and bilateral annulus for correction of a focal kyphotic lumbar deformity.

Conclusions

ACR can be performed with a complete ALL release under direct visualization using the ATP approach. This technique can be a safe and effective method for achieving substantial correction of a focal kyphotic deformity within the lumbar spine.

Acknowledgments

Funding: None.

Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jss.amegroups.com/article/view/10.21037/jss-23-84/rc

Data Sharing Statement: Available at https://jss.amegroups.com/article/view/10.21037/jss-23-84/dss

Peer Review File: Available at https://jss.amegroups.com/article/view/10.21037/jss-23-84/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jss.amegroups.com/article/view/10.21037/jss-23-84/coif). RAWM reports that he is a paid presenter and speaker of DePuy, A Johnson & Johnson Company, and received IP royalties from Globus Medical. 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. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by institutional review board of Houston Methodist Hospital (No.

PRO00032736) and individual consent for this retrospective analysis was waived.

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Cite this article as: Hirase T, Vemu SM, Shin C, Marco RAW. Anterior column realignment (ACR) for focal kyphotic spinal deformity using an anterior to psoas approach and anterior longitudinal ligament release. J Spine Surg 2023;9(4):422-433. doi: 10.21037/jss-23-84