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Reviewer A

Overall, this is a well-written surgical technique article with an operative report that provides a detailed step-by-step description of delivering an ACR using a lateral approach at L1-L2. However, there are major revisions that should be made prior to re-consideration for publication.

Comment 1: Line 12 and 27: typically there is no psoas muscle fibers at the L1-L2 at the level of the lateral disc space, thus would not need to go transpsoas at this level. Furthermore, in the presented case, the dilator was placed directly on the L1-L2 disc space at the 50-yard line without going transpsoas. Thus, this technique should be described as a lateral retropleural approach as described in line 61 to be consistent.

Reply 1: We appreciate the reviewers' comments and have modified our text to reflect the lateral retropleural approach of our surgery. We have modified our text as advised (Please see page 1 line 12, and page 2, line 6)

Changes in the text: Page 1 Line 12 "transpsoas approach" was changed to "lateral approach". Page 2 Line 6 "transpsoas approach" was changed to "retroperitoneal or retropleural approach (depending on level)"

Comment 2: Lines 40-57: With the current evidence in deformity correction principles, there is an extremely narrow indication for performing an L1-L2 ACR. This intervention 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. Unfortunately, the patient presented in this case had a PI of 46 degrees, LL of 21 degrees with a L4-S1 LL of ~0 (this was not provided in the manuscript and was measured from a screenshot off the video presentation). Thus, creating a different deformity in an attempt to correct a L4-S1 flatback. Misplacing the apex of this lordosis cranially with increase upper lordotic with now creates a new mismatch the lower kyphotic arc of the thoracic spine, which has been shown to lead to PJK and PJF. At a minimum, this limitation must be discussed within a discussion section of this article, which currently doesn't exist. If the authors are promoting a minimally invasive approach for a sick patient that cannot tolerate an low lumbar PSO for this patient, this should be also described within the discussion section.

Reply 2:

Thank you for your insightful comments regarding our manuscript. We appreciate you pointing out the importance apex placement in the lumbar spine and we have added a discussion. 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. There is evidence suggesting that GAP scores, lumbar disability index are not associated with long-term outcomes. Additionally, the authors have a large series of upper lumbar ACR patients of whom none developed PJF (manuscript in preparation). We have added this discussion to our manuscript beginning on page 8 line 3.

Changes in the text:

Page 8 line 3:

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) (1, 2). PI-LL mismatch correlates strongly with SVA, and good outcomes require balanced sagittal alignment (3). Roussouly et al. proposed the use of pelvic incidence (PI) as a basis for determining lumbar morphology in the normative physiologic spine.(4, 5) 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 (6). 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 lumbar lordosis (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(7). 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 LDI (8). Kwan et al. in an external validation study done by the AO Spine and Scoliosis Research Society, however, did not demonstrate increased risk of mechanical complications with higher GAP scores at 2-years(7). Im et al. concluded in a retrospective review of 228 consecutive cases of 8-segment T10-S1 PSF with PSO or multi-level SPO 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(9). 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 versus L3) (10). Finally, the authors of this manuscript have a forthcoming series of 20 upper lumbar ACR patients, of whom none developed PJF (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.

1. Schwab F, Ungar B, Blondel B, Buchowski J, Coe J, Deinlein D, et al. Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study. *Spine*. 2012;37(12):1077-82.
2. Schwab FJ, Blondel B, Bess S, Hostin R, Shaffrey CI, Smith JS, et al. Radiographical spinopelvic parameters and disability in the setting of adult spinal deformity: a prospective multicenter analysis. *Spine*. 2013;38(13):E803-12.
3. Takemoto M, Boissière L, Vital JM, Pellisé F, Perez-Grueso FJS, Kleinstück F, et al. Are sagittal spinopelvic radiographic parameters significantly associated with quality of life of adult spinal deformity patients? Multivariate linear regression analyses for pre-operative and short-term post-operative health-related quality of life. *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European*

Section of the Cervical Spine Research Society. 2017;26(8):2176-86.

4. Roussouly P, Gollogly S, Berthonnaud E, Dimnet J. Classification of the normal variation in the sagittal alignment of the human lumbar spine and pelvis in the standing position. *Spine*. 2005;30(3):346-53.

5. Roussouly P, Nnadi C. Sagittal plane deformity: an overview of interpretation and management. *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society*. 2010;19(11):1824-36.

6. Pesenti S, Lafage R, Stein D, Elysee JC, Lenke LG, Schwab FJ, et al. The Amount of Proximal Lumbar Lordosis Is Related to Pelvic Incidence. *Clin Orthop Relat Res*. 2018;476(8):1603-11.

7. Kwan KYH, Lenke LG, Shaffrey CI, Carreon LY, Dahl BT, Fehlings MG, et al. Are Higher Global Alignment and Proportion Scores Associated With Increased Risks of Mechanical Complications After Adult Spinal Deformity Surgery? An External Validation. *Clin Orthop Relat Res*. 2021;479(2):312-20.

8. Yilgor C, Sogunmez N, Boissiere L, Yavuz Y, Obeid I, Kleinstück F, et al. Global Alignment and Proportion (GAP) Score: Development and Validation of a New Method of Analyzing Spinopelvic Alignment to Predict Mechanical Complications After Adult Spinal Deformity Surgery. *The Journal of bone and joint surgery American volume*. 2017;99(19):1661-72.

9. Im SK, Lee KY, Lim HS, Suh DU, Lee JH. Optimized Surgical Strategy for Adult Spinal Deformity: Quantitative Lordosis Correction versus Lordosis Morphology. *J Clin Med*. 2021;10(9).

10. Lafage V, Schwab F, Vira S, Hart R, Burton D, Smith JS, et al. Does vertebral level of pedicle subtraction osteotomy correlate with degree of spinopelvic parameter correction? *Journal of neurosurgery Spine*. 2011;14(2):184-91.

Comment 3: Line78, 82: Describe length/orientation of incision (e.g. 5 cm transverse incision in line with the disc space)

Reply 3: Thank you for this comment. We have added more details to the text. (Please see page 4, line 6)

Changes in the text: On line 78 (page 4, line 6), we have added the following text “A four centimeter transverse incision in line with the disc space.”

- In conclusion, this surgical technique paper has a place within the literature to provide a step-by-step guide for surgeons to perform this surgery; however, for a different patient than the one that was selected for this paper. Furthermore, the limitations of this surgery must be discussed in detail as a separate discussion.

Reviewer B

Your manuscript is interesting and well-documented. However, I have some points of concern:

Comment 1: I believe the title is not representing properly the manuscript. MIS-ACR, but in combination with a open posterior approach

Reply 1: We have changed the title to better represent the surgery as a combination of a minimally invasive lateral surgery and an open posterior surgery. (See page 1 line 1). This is also changed in the video title slide

Changes in the text: “Surgical Technique of Combined Minimally Invasive Anterior Column Realignment at L1-L2 with Open Extension of Prior Fusion”

Comment 2: The step-by-step description of the ACR and Stage II is providing excessively basic and unnecessary information for an advanced surgical procedure

Reply 2: We appreciate the close reading of our text. We have looked at our detailed descriptions and have eliminated the more basic information in our manuscript. Please see following: page 5, line 10, line 16, and line 17 and page 6 line 14.

Changes in the text:

- On page 5, line 10 the following text was deleted “The parietal pleura, deep muscular and fascial layers were closed with 0 Vicryl sutures. The subcutaneous fat was closed with 2-0 Vicryl sutures. The dermis was closed with 3-0 Vicryl sutures. The skin was closed with staples. The wound was dressed sterilely.” This was replaced with the briefer “and the tissues were closed in layers”
- On page 5 line 16 the following text was deleted “including wrists, elbows, breasts, iliac creasts, thighs, knees, and feet.”
- On page 5 line 17 the following text was deleted. “This planned incision, which incorporated her previous scar, was then prepped and draped in the usual sterile fashion. Local anesthetic was administered.”
- On page 6 line 14 the following text was deleted. “The setscrews were the final tightened”
- On page 6 line 21 the following text was deleted “A 7 flat JP drain was tunneled superiorly and sutured to the skin. The wound was then closed in layers with 0 Vicryl sutures in the fascia, 2-0 Vicryl sutures in the subcutaneous fat, 3-0 Vicryl sutures in the dermis, and staples in the skin. The wound was dressed sterilely. The patient was returned supine to her stretcher” This text was replaced with “A drain was tunneled superiorly to the skin, and the wound was then closed in layers.”

Comment 3: Please, clarify when was performed the second stage of the surgery, the same day? How many days in between?

Reply 3: Yes, the second stage of the surgery was performed on the same day. We have modified our text to include this information (Please see page 3, line 17)

Changes in the text: On page 3, line 17 we have added “Both surgery stages were to be performed on the same day.”

Comment 4: The first stage was performed in a left side up position. However, the video is showing a right side up position if cranial is on the left side of the screen and anterior on the superior part of the screen

Reply 4: We appreciate the close review of the video and on our re-submitted video the placement of the cranial label is moved to the right side of the screen.

Changes in the text: none

Comment 5: The comprehensive ACR classification system by Juan Uribe - Frank Schwab was not cited, and considering the PCO done (Schwab modifier), your case is a Grade 2 construct. This important information could be added to the manuscript or to the video, or both

Reply 5: Thank you for this suggestion. We have included our discussion to discuss the ACR classification and have incorporated the recommended citation into our paper as well as the following text on page 7 line 16.

- Uribe JS, Schwab F, Mundis GM, Xu DS, Januszewski J, Kanter AS, Okonkwo DO, Hu SS, Vedat D, Eastlack R, Berjano P, Mummaneni PV. The comprehensive anatomical spinal osteotomy and anterior column realignment classification. *J Neurosurg Spine*. 2018 Nov 1;29(5):565-575. doi: 10.3171/2018.4.SPINE171206. PMID: 30141765.

Changes in the text:

Page 7 line 16: “Spinopelvic disharmony contribute 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 (1). 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 (2). 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) (4).”

1. Uribe JS, Schwab F, Mundis GM, Xu DS, Januszewski J, Kanter AS, et al. The comprehensive anatomical spinal osteotomy and anterior column realignment classification. *Journal of neurosurgery Spine*. 2018;29(5):565-75.
2. Schwab F, Blondel B, Chay E, Demakakos J, Lenke L, Tropiano P, et al. The comprehensive anatomical spinal osteotomy classification. *Neurosurgery*. 2014;74(1):112-20; discussion 20.
3. Uribe JS, Harris JE, Beckman JM, Turner AW, Mundis GM, Akbarnia BA. Finite element analysis of lordosis restoration with anterior longitudinal ligament release and lateral hyperlordotic cage placement. *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society*. 2015;24 Suppl 3:420-6.
4. Akbarnia BA, Mundis GM, Jr., Moazzaz P, Kabirian N, Bagheri R, Eastlack RK, et al. Anterior column realignment (ACR) for focal kyphotic spinal deformity using a lateral transpsoas approach and ALL release. *J Spinal Disord Tech*. 2014;27(1):29-39.

Reviewer C

Comment 1: I suggest to give more details about technical explanation on the Smith-Peterson

osteotomies

Reply 1: Thank you. We have included a discussion of the posterior column osteotomy, the Schwab classification on page Page 7 line 16

Changes in the text:

Page 7 line 16 “Spinopelvic disharmony contribute 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 (1). 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 Scwab et al., and ranges from grade 1 to grade 6 based on increasing anatomic resection (2). 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) (4).”

1. Uribe JS, Schwab F, Mundis GM, Xu DS, Januszewski J, Kanter AS, et al. The comprehensive anatomical spinal osteotomy and anterior column realignment classification. *Journal of neurosurgery Spine*. 2018;29(5):565-75.
2. Schwab F, Blondel B, Chay E, Demakakos J, Lenke L, Tropiano P, et al. The comprehensive anatomical spinal osteotomy classification. *Neurosurgery*. 2014;74(1):112-20; discussion 20.
3. Uribe JS, Harris JE, Beckman JM, Turner AW, Mundis GM, Akbarnia BA. Finite element analysis of lordosis restoration with anterior longitudinal ligament release and lateral hyperlordotic cage placement. *European spine journal : official publication of the European Spine Society, the European Spinal Deformity Society, and the European Section of the Cervical Spine Research Society*. 2015;24 Suppl 3:420-6.
4. Akbarnia BA, Mundis GM, Jr., Moazzaz P, Kabirian N, Bagheri R, Eastlack RK, et al. Anterior column realignment (ACR) for focal kyphotic spinal deformity using a lateral transpsosas approach and ALL release. *J Spinal Disord Tech*. 2014;27(1):29-39.