

Top-ten most-cited articles on anterior column release in the context of minimally invasive lumbar interbody fusion

ABSTRACT

Introduction: Lateral anterior column release (ACR) is a minimally invasive option for the correction of sagittal plane deformity. To assemble a homogeneous picture of published research on ACR, an advanced bibliometric analysis was conducted to compile the top-ten most-cited articles on the topic of ACR.

Methods: A keyword search using the Thomson Reuters Web of Knowledge was conducted to identify articles discussing the role of lateral ACR. The articles were then ranked based on the total number of citations to identify the ten most-cited articles published. A subjective appraisal of the findings of these articles was conducted to provide a ranked literature review and to examine trends in the study of ACR between 2012 and 2019.

Results: The earliest published article on ACR was in 2012 by Deukmedjian *et al.* Three articles were *in vitro* biomechanical assessments of ACR, and seven articles were on outcome analyses, which were either case series or case controlled. The most-cited article was a biomechanical study authored by Uribe *et al.* The article with the highest rate of citations/year was authored by Manwaring *et al.* Uribe and the *European Spine Journal* were the most frequently cited author and journal, respectively.

Conclusions: The lateral ACR approach has enjoyed significant scholarly attention since its advent. Higher-level analyses with robust control groups, larger sample sizes, and long-term follow-up are necessary to improve our understanding of this approach.

Keywords: Anterior column realignment, anterior column reconstruction, anterior column release, bibliometrics

INTRODUCTION

Lateral anterior column release (ACR) is a minimally invasive (MI) technique that can afford large sagittal balance correction, equivalent to pedicle subtraction osteotomy (PSO).^[1] Since its advent in 2012, lateral ACR has gained increased traction. However, there is a scarcity of comprehensive meta-analyses or literature reviews on the topic of lateral ACR in practice. We performed a citation analysis of ACR since its advent to inform future efforts to systematically review and meta-analyze published works on ACR. This study aims to create a homogeneous picture of published research on lateral ACR, and therefore, an advanced bibliometric analysis was conducted to assemble the top-ten most-cited articles on the topic of ACR.

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METHODS

Data collection

An advanced inquiry was made of the Reuters Web of Science for articles that explicitly stated the terms, “Anterior column release,” “Anterior column reconstruction,” or “Anterior column realignment,” with the search term depicted in Figure 1. Only journal articles published in English between 1945 and 2020 were queried for. This search yielded 37 articles, of which the final ten articles were assembled.

Inclusion criteria

Utilizing the Reuters Web of Science database, an advanced search was conducted to identify highly cited articles that explicitly discussed ACR, reconstruction, or realignment. All journals and databases within the Reuters Web of Science were queried.

All non - article research contributions were excluded from the database. Contributions in languages other than English were excluded. Studies that discussed interventions unrelated to the topic at hand were excluded, with the remaining included papers deemed to be relevant and highly cited.

Of the 15 remaining articles published between 2012 and 2019, those with ten or fewer citations were removed from the final top-ten list and will be referred to as accessory, yielding a final list of 10. The five accessory articles were analyzed to assess upward citation trends, relevance to the advancement of ACR, and changes in evidence type, but were not included in the final list of top-cited articles on ACR.

RESULTS

The most frequently cited articles were published between 2012 and 2017; on average, these articles were cited 5.6 times/year. With respect to citation rate, the least frequently cited article included in the top-ten received 3.8 citations/year, was published by Uribe *et al.* in 2015,^[2]

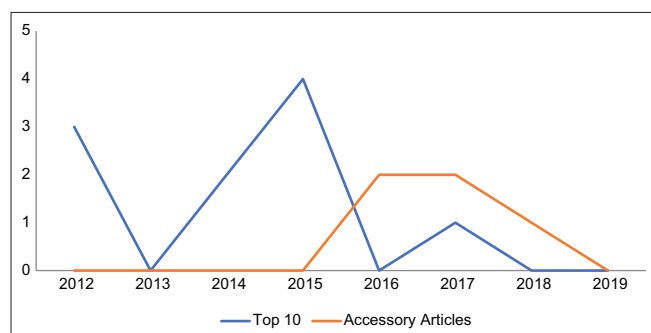


Figure 1: The number of top-ten articles published/year

and discussed a biomechanical model for anterior longitudinal ligament release and resection that achieved improvements in segmental lordosis (SL). The article with the highest citation rate was authored by Manwaring *et al.*^[3] and examined sagittal plane correction following MI ACR, which has been cited on average 7.43 times/year since 2012.

The respective total citation rank, authors, article title, topic, summary, study type, level of evidence, total citation count, citation rate, peak citation year, and peak citation quantity were recorded for the top-ten most-cited articles and for the accessory articles [Tables 1 and 2].

The publication years of the articles ranged between 2012 and 2019. Half of the articles included in the final analysis were published between 2012 and 2014 [Table 1], with the remaining being published between 2015 and 2019. The peak year for publications was 2015 when four articles in the top 10 were published [Figure 1].

The *European Spine Journal* was the best-represented journal, having published four of the top-ten most-cited articles on the topic of ACR, which was closely followed by the *Journal of Neurosurgery – Spine*, in which three of the top cited articles were published. The *Journal of Spinal Disorders & Techniques*, *Scientific World Journal*, and *World Neurosurgery* each published 1 of the top-ten most-cited articles.

Overwhelmingly, the best-represented author in the top 10 was Juan Uribe, M.D., currently of Barrow Neurological Institute, and formerly the University of Southern Florida, who was credited with authorship six times among the top-ten most-cited articles [Figure 2].

Articles included in the top ten originated from three countries [Figure 3] but were predominantly published by institutions and authors originating from the United States. The most productive institution was the University of Southern Florida, having contributed to six publications in the top 10, closely followed by authors affiliated with the San Diego Center for Spinal Disorders (4 authorship affiliations) and Scripps Clinic (3 authorship affiliations).

The most-cited article (60 citations) pertaining to the topic of ACR was the cadaveric study authored by Uribe *et al.*^[4] The article with the highest citation rate was the 2014 case series authored by Manwaring *et al.*,^[3] having been cited on average 10.4 times/year since its publication [Table 1].

Table 1: Top-ten citations

Rank	Authors	Article title	Article summary	Study type	Level of evidence	Reuters citations	Citation rate	Peak citation year	Peak citation quantity
1	Uribe <i>et al.</i> ^[4]	Lordosis restoration after anterior longitudinal ligament release and placement of lateral hyperlordotic interbody cages during the minimally invasive lateral transpoas approach: a radiographic study in cadavers	Observational analysis of the selective ALL release and usage of lordotic implants through an extreme lateral interbody fusion approach on nine cadaveric specimens	Cadaver study	V	60	8.57142857	2015	13
2	Deukmedjian <i>et al.</i> ^[5]	Early outcomes of minimally invasive anterior longitudinal ligament release for correction of sagittal imbalance in patients with adult spinal deformity	Retrospective analysis of patients that underwent treatment with ALL release via MI LIF for thoracolumbar deformity	Case series	IV	54	7.71428571	2018	12
3	Manwaring <i>et al.</i> ^[3]	Management of sagittal balance in adult spinal deformity with minimally invasive anterolateral lumbar interbody fusion: a preliminary radiographic study	A retrospective review of 36 patients to assess the effects of MI anterior column release on spinopelvic parameters, compare the radiographic effect of MI-ACR with PSO and SPO for treatment of adult spinal deformity and investigate the radiographic effect of percutaneous posterior spinal instrumentation on spinopelvic parameters when combined with MI transpoas LIF for adult spinal deformity	Case series	IV	52	10.4	2018/2019	10
4	Akbarnia <i>et al.</i> ^[6]	Anterior column realignment (ACR) for focal kyphotic spinal deformity using a lateral transpoas approach and ALL release	Seventeen patients underwent anterior column realignment using a lateral transpoas approach with release of ALL for correction of focal kyphotic deformity; preliminary results of ACR showed similar correction capacity and similar rate of morbidities for the treatment of focal kyphotic spinal deformity	Case series	IV	48	9.6	2018	10
5	Deukmedjian <i>et al.</i> ^[7]	Anterior longitudinal ligament release using the minimally invasive lateral retroperitoneal transpoas approach: a cadaveric feasibility study and report of 4 clinical cases	Observational analysis of the feasibility of MI lateral retroperitoneal transpoas approach for ALL release on 12 cadaveric specimens	Cadaver study	V	41	5.85714286	2015/2017	9
6	Berjano <i>et al.</i> ^[8]	Anterior column realignment from a lateral approach for the treatment of severe sagittal imbalance: a retrospective radiographic study	Preoperative and postoperative full-standing X-rays of 12 patients who underwent anterior column realignment were retrospectively reviewed; the mean preoperative and postoperative lumbar lordosis values were, respectively, $-20^{\circ} \pm 17^{\circ}$ and $-51^{\circ} \pm 9.8^{\circ}$ ($P < 0.001$), while a mean value of 27° of lordosis were restored at a single anterior column realignment level	Case series	IV	37	9.25	2017	11

Contd...

Table 1: Contd...

Rank	Authors	Article title	Article summary	Study type	Level of evidence	Reuters citations	Citation rate	Peak citation year	Peak citation quantity
7	Turner et al. ^[9]	Radiographic outcomes of anterior column realignment for adult sagittal plane deformity: a multicenter analysis	A multicenter database was queried from 2005 to 2013 for patients with ASD treated with anterior column realignment. Anterior column realignment successfully restores lumbar lordosis in patients with ASD with sagittal imbalance. Anterior column realignment results in greater segmental correction than is achieved with LLIF alone	Case series	IV	35	8.75	2017	9
8	Murray et al. ^[10]	Complications and neurological deficits following minimally invasive anterior column release for adult spinal deformity: a retrospective study	Thirty-one patients underwent a total of 47 MI-anterior column releases; discussion of complications and technical demand	Case series	IV	28	7	2017	8
9	Uribe et al. ^[2]	Finite element analysis of lordosis restoration with anterior longitudinal ligament release and lateral hyperlordotic cage placement	A three-dimensional model of a L3-4 segment was used. Disc distraction was simulated by inserting interbody cages mid-body in the disc space; "conclusion: Increased segmental lumbar lordosis is achievable with hyperlordotic cages after ALL resection"	Bench research	V	23	5.75	2018	6
10	Mundis et al. ^[11]	Anterior Column Realignment has Similar results to Pedicle Subtraction Osteotomy in Treating Adults with Sagittal Plane Deformity	A case-control study of 17 patients comparing ACR and PSO; anterior column realignment achieved similar radiographic results as PSO in a matched cohort with significantly less estimated blood loss and similar overall complication rate	Case-control	III	17	8.5	2019	7

SL - Segmental lordosis; MI - Minimally invasive; LIF - Lateral interbody fusion; PSO - Pedicle subtraction osteotomy; SPO - Smith-Petersen osteotomy; ASD - Adult spinal deformity; LLIF - Lateral lumbar interbody fusion; ALL - Anterior longitudinal ligament

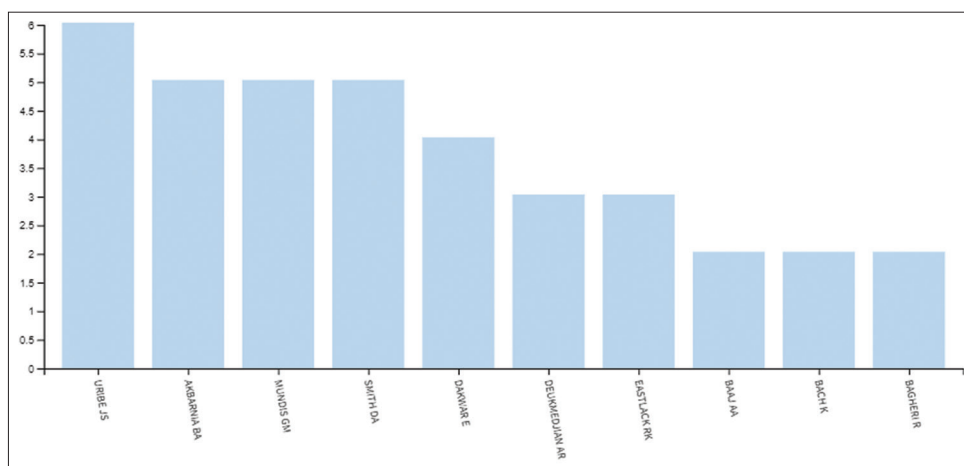


Figure 2: Top contributing authors to the top-ten most-cited articles

DISCUSSION

Literature review

To date, relatively few reviews, bibliometric studies, or meta-analyses have been published on the topic of ACR. A literature review of PubMed reveals only three such

articles that partially include or are entirely focused on the comprehensive analysis of existing literature for ACR. The most comprehensive overview of ACR execution was published in 2018 by Xu et al.,^[16] but their review focuses primarily on published trends in the technique and implementation of ACR rather than holistic trends.

Table 2: Accessory articles

Rank	Authors	Article title	Article summary	Study type	Level of evidence	Reuters citations	Citation rate	Peak citation year	Peak citation quantity
A1	Hosseini <i>et al.</i> ^[12]	Preliminary results of anterior lumbar interbody fusion, anterior column realignment for the treatment of sagittal malalignment	A retrospective study of 39 patients treated with ALIF anterior column realignment was performed. The clinical and radiographic outcomes at 1-year follow-up were satisfactory	Case series	IV	10	5	2019/2020	4
A2	Leveque <i>et al.</i> ^[13]	Correction of severe spinopelvic mismatch: Decreased blood loss with lateral hyperlordotic interbody grafts as compared with pedicle subtraction osteotomy	The authors compare peri- and postoperative measures in two groups of patients undergoing correction of a sagittal plane imbalance, either through PSO or the use of lateral lumbar fusion and anterior column realignment with hyperlordotic (20°–30°) interbody cages. Patients undergoing deformity correction with LLIF and anterior column realignment were able to attain comparable outcomes, albeit with significantly reduced blood loss, to patients undergoing PSO	Case-control	III	10	5	2019	4
A3	Melikian <i>et al.</i> ^[14]	Sagittal Plane Correction Using the Lateral Transposas Approach: A Biomechanical Study on the Effect of Cage Angle and Surgical Technique on Segmental Lordosis	The authors subjected cadaveric specimens to compressive loads, under several conditions, to determine the changes that could be attained in sagittal alignment. They identified that a 30° cage combined with the release of the anterior longitudinal ligament resulted in a modest increase in lordosis, with the most increase reported after performing an additional spinous process resection and facetectomy.	Cadaveric study	V	10	3.3333333	2018/2019	4
A4	Uribe <i>et al.</i> ^[11]	The comprehensive anatomical spinal osteotomy and anterior column realignment classification	The authors propose a classification system for anterior column realignment and its variants based on the construct used, along with a Schwab and approach modifier	N/A	N/A	8	8	2020	6
A5	Demirkiran <i>et al.</i> ^[15]	Adult Spinal Deformity Correction with Multi-level Anterior Column Releases: Description of a New Surgical Technique and Literature Review	Eight adults with spinal deformity who underwent multilevel ACRs (≥ 2) followed by open posterior instrumentation with a minimum 1-year follow-up were retrospectively reviewed. No significant changes in the spinopelvic parameters were noted after the second stage, when compared to the values noted after the first stage. Favorable improvements in patient-reported outcome measures were obtained	Case series	IV	8	2.6666666	2018/2019	3

SL - Segmental lordosis; ACR - Anterior column release; PSO - Pedicle subtraction osteotomy; LLIF - Lateral lumbar interbody fusion; N/A – Not available; ALIF - Anterior lumbar interbody fusion; ALL - Anterior longitudinal ligament

Another review published in 2019 by Cheung *et al.*^[17] is methodologically similar to our work but crucially differs in that it excludes all biomechanical models or cadaveric studies of ACR, which we wished to capture in our analysis to develop a full picture of how the study of ACR has evolved over time. Finally, a literature review and a technical description were included in a 2016 case series authored by Demirkiran *et al.*^[15] their review was limited in that it focused only on other case

series that discussed the impact of ACR on certain measures of sagittal plane deformity. The 2016 article is also briefly mentioned below in our discussion of the accessory articles.

Therefore, to our knowledge, no broad study of all of the literature on ACR or ALL (anterior longitudinal ligament) release has been conducted, rendering this work novel. We believe that this work is necessary to properly

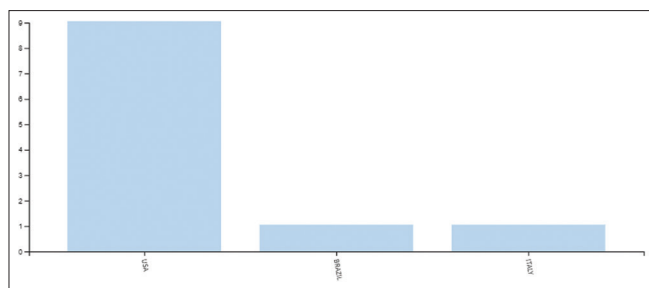


Figure 3: Nation of origin of top-ten most-cited articles

inform future efforts to systematically review or meta-analyze publications on the topic of ACR.

In vitro studies

Of the top-ten most-cited papers on the topic of ACR, three were *in vitro* studies, two of which were cadaveric studies published in 2012 of radiographic analysis following ACR implementation; the remaining study was a biomechanical three-dimensional (3D) modeling of ACR published in 2015 that evaluated segmental correction of lumbar lordosis (LL). The level of evidence of all three of these articles was V, receiving a total of 124 citations between 2012 and 2019.

Overall, the article that received the most citations (60) on the topic of ACR was the 2012 *in vitro* cadaveric study published by Uribe *et al.* in the *European Spine Journal*.^[4] Utilizing nine frozen cadaveric specimens, Uribe *et al.* demonstrated the earliest preliminary evidence *in vitro* that ALL release and subsequent lateral lordotic interbody cage placement could achieve segmental gains in LL.^[4] This result was replicated *in vitro* by Uribe *et al.* in an 2015 biomechanical study utilizing finite element analysis and 3D simulation analysis.^[2]

Utilizing a 3D model, the authors analyzed the biomechanics of the L3-L4 junction under four varying anterior longitudinal ligament condition sets: one, intact ALL; two, release of the ALL; three, release of ALL and facetectomy; and four, ALL release with posterior column osteotomy.^[2] Alterations in SL, disc height, and foraminal height and area were analyzed. The authors found that ACR and the introduction of increasingly lordotic cages produced proportional increases in SL; posterior column osteotomy increased SL, but reduced posterior disc heights to the point that spinous processes began to come in contact with each other and inhibit further angulation. Despite the promising results, the authors conceded that optimal cage design could only be fully elucidated by clinical application and subsequent outcome analysis.

The final *in vitro* study in the top ten was also published in 2012 by Deukmedjian *et al.*, for which Uribe was a co-author,

in the *Journal of Neurosurgery – Spine*.^[7] Preliminary results were collected from 48 cadaveric lumbar spine segments that underwent ALL through the MI lateral retroperitoneal approach; as an adjunct, the authors also assembled four clinical cases to serve as a preliminary *in vitro* clinical experience to supplement the findings from the cadaveric study.

The cadaveric evidence from this study assessed the biomechanical feasibility of ACR from the MI lateral transpoas retroperitoneal approach and the mean correction in SL at various lumbar levels. The authors found the stated approach for ACR to be viable, however mentioned that special attention should be paid to protect the nearby, vulnerable structures (i.e., great vessels of the lower extremity, sympathetic plexus).

The clinical arm of Deukmedjian *et al.* work comprised an *in vivo* experience of four patients. The four-patient series revealed promising reductions in intraoperative duration and blood loss, relative to the traditional posterior open (PO) approaches, taking on average 56 min for each patient, and incurring 40 mL of blood loss.^[7] They found mean increases in SL of 10.2°/level and mean increases of global LL of 25°. Measures of postoperative disability, such as the Oswestry Disability Index and Visual Analog Scale, improved by 35 and 9 points, respectively. In the same year, Deukmedjian *et al.* also examined seven patients who underwent MIS lateral, retroperitoneal, transpoas approach and found an average in global SL of 24° and 17°.^[5] They also noted an improvement in sagittal balance and postoperative disability that was comparable to the aforementioned study.

In vivo studies

The most frequently cited article [10.4 citations/year, Table 1] by Manwaring *et al.* was a retrospective radiographic review examining sagittal plane correction through changes in prior and postoperative spinopelvic parameters.^[3] Their work constituted a case series comparing the outcomes of standalone ACR and MI-lateral interbody fusion (LIF) with traditional posterior approaches, such as PSO or Smith-Petersen osteotomies (SPOs). Results of their analysis demonstrated MI-LIF with ACR achieved corrections in sagittal vertical axis (SVA) by 3.1 cm and LL by 12.0° for each level treated. The addition of posterior instrumentation did not alter radiographic parameters.^[3] The authors concluded that further analysis was required to assess limitations on sagittal balance correction over multiple levels, along with adequate durability testing to evaluate the safety of MI-LIF with ACR in adult spinal deformity (ASD) surgery. To date,

their work has been cited 52 times, and at a rate of 7.43 times/year. The years in which it was cited most frequently were 2018 and 2019, when it was cited ten times each.

In the same year, Akbarnia *et al.* published a retrospective review on the efficacy of ACR in the context for correction of focal kyphotic deformity in adults.^[6] Our analysis revealed this article to have been cited 48 times, an average of 6.86 times/year since its publication. Its peak citation year was 2018 when it was cited ten times. Given the well-documented long operative times, neurological complications, and morbidity and mortality profile of traditional open approaches (PSO, SPO, and vertebral column resection [VCR]), the authors evaluated if MI alternatives could achieve similar corrections in LL, motion segment angle, and T1 spinopelvic inclination (T1SPI) to that of PSO, SPO, and VCR.

The preoperative average for motion segment angle improved from 9° to -19° following stand-alone ACR and to -26° following posterior instrumentation. The mean LL improved from -16° preoperatively to -38° following ACR and to -45° following posterior instrumentation.^[6] The mean pelvic tilt (PT) reduced from the preoperative mean of 34° to 24° following combined ACR-posterior open approaches. Among patients with negative preoperative T1SPI, ACR produced improvements from -6° to -2°; for those with neutral or positive T1SPI, the average improvement was 8°.

In March 2015, Turner *et al.* published an analysis constituting the first multicenter evaluation of ACR, signifying a watershed in the study of ALL release, and its value as an augmenting force to improve the correction capacity for lateral lumbar interbody fusion (LLIF).^[9] The authors carried out a retrospective radiographic analysis between 2005 and 2013 of 34 patients treated for sagittal imbalance at five centers, and recorded LL, pelvic incidence, pelvic incidence-LL mismatch (PI-LL), PT, T1SPI, and sacral slope. Overwhelmingly statistically significant changes were associated with LL and PI-LL, with a 20° reduction postoperatively (-26.7° to -46.7°) in the former case and a 25° reduction PI-LL (29.4° to 5.5°); a narrowly statistically significant reduction was also revealed for PT, which was lowered by approximately 7° (28.3° to 21.6°).^[9] Our analysis revealed this article to have been cited 35 times, an average of 5.83/year since its publication; its peak citation year was 2017, when it was cited 9 times.

Only a month later, in April 2015, Berjano *et al.* partially replicated these results, demonstrating large improvements in LL following ACR for sagittal malalignment.^[8] Through retrospective analysis of prospectively collected standing X-rays of 11 patients undergoing LLIF with ALL release,

LL improved from -20° to -51° on average, with a mean single-level lordotic increase of 27°.^[8] Our analysis revealed this article to have been cited 37 times, an average of 6.17/year since its publication; its peak citation year was 2017, when it was cited 11 times.

The only case-control study yielded by our analysis was published by Mundis *et al.* in 2017.^[11] The study compared outcomes and complications in matched cohorts of patients undergoing ACR or PSO. It is also the youngest article in the top 10, given its publication year [Table 1], and has been cited at a relatively high rate [8.5 times/year, 17 total citations, Table 1]. This shift toward case-control studies on the topic at hand demonstrates an exciting new shift in the study of ACR, yielding higher-quality evidence, and greater explanatory power.^[11] Their work demonstrates that blood loss was significantly lower in the ACR group than in the PSO group (1.6 vs. 3.6 L, respectively) but found no meaningful difference in the overall complication rate (35.3% vs. 41.2%). Interestingly, they found that outcomes following ACR were superior to those of PSO in many postoperative metrics of sagittal balance.

At the final follow-up, PT changed from 34° to 25° in the ACR group, demonstrating greater correction than in the PSO group (31° to 28°).^[11] Conversely, the PSO group developed significantly greater correction in T1SPI (8° vs. 1.9°) than in the ACR group. These mixed results suggest that ACR may have a role in augmenting MI lateral approaches but also in supplementing posterior open approaches.

The final *in vivo* article included in our analysis was authored by Murray *et al.* and published in 2015, representing one of the largest studies by patient size (31), and by far the largest study of total ACRs performed (47).^[10] Preoperative measurements of spinopelvic parameters were made on 36" scoliosis films for all patients, recording a mean LL of 17.6°, PT of 4.3°, coronal Cobb angle of 13.9°, and average SVA of 3.8 cm.^[10] The key finding of their work demonstrated that although ACR may yield improvements in global sagittal alignment while also reducing blood loss and tissue disruption, these advantages come at the cost of high rates of catastrophic complications (19%, 9/47 ACRs).

Trends

The first generation of literature on ACR appears to have occurred between 2012 and 2014 [Table 1 and Figure 1] and was primarily composed of biomechanical and cadaveric studies evaluating the viability of ACR. Qualitative analysis reveals a transition from largely *in vitro* studies that occurred in 2015, with almost all top-cited studies from then on to

the conclusion of our analysis constituting case series or case–control studies utilizing level IV evidence or higher. This second generation of studies seems to focus on outcome evaluation and complication profiles *in vivo* rather than feasibility *in vitro*.

Therefore, it is the author’s opinion that the feasibility of ACR appears to have been largely accepted by scholars of MI surgery for ASD, with focus now having largely shifted to outcome analysis and better characterization of complication profiles. However, for full characterization of the safety and efficacy that ALL release may play in augmenting existing lateral MI approaches, or in supplementing existing PO approaches, studies with robust control groups, larger sample sizes, and data collected from multiple centers are necessary.

Accessory articles

Our analysis yielded five more articles on the topic of ACR, but due to their relatively low level of citations (fewer than 10), we excluded them from the final analysis. Two of these articles were case series, the first of which was authored by Demirkiran *et al.*,^[15] which examined staged surgery for ASD involving both ACR and open posterior approaches in eight patients; the other was a relatively large case series (39 patients) demonstrating satisfactory radiographic outcomes following anterior lumbar interbody fusion with ACR, authored by Hosseini.^[12]

The remaining *in vivo* study of these accessory publications was authored by Leveque *et al.*^[13] in 2017, which was the second case–control yielded from our analysis, but did not achieve a high enough citation count to be included in the top-ten list. The study demonstrated that patients undergoing deformity correction with LLIF and anterior column realignment were able to attain comparable outcomes, albeit with significantly reduced blood loss, to patients undergoing PSO.^[13]

One *in vitro* study was excluded from our analysis, which was a cadaveric study by Melikian published in 2016 that analyzed the effect that varying cage angles had on postimplantation SL.^[14] They found that there was no difference in resulting lordosis between the use of parallel (0°) or 10° cages; however, a 30° cage resulted in a slight increase in SL.^[14]

The final study was authored by Uribe *et al.* in 2018, and can be neither classified as *in vitro* nor *in vivo*; it proposed a classification system based on technical complexity and invasiveness for ACR and its variants.^[1] This study has by far

the highest citation rate (8.0 times/year) among the accessory studies yielded from our analysis, having been published in 2018, and cited eight times before the conclusion of the analysis [Table 2].

The earliest published article among these excluded works was the 2016 study authored by Melikian *et al.*^[14] This result, taken together with the finding that the peak citation year for all of the accessory studies occurred between 2018 and 2019, suggests that although their current citation levels are lower than what we deemed worthy for final inclusion, future analysis may demonstrate their relevance to the study of ACR. This is especially true of the 2018 classification system proposed by Uribe *et al.*, which has a citation rate greater than nearly half of the included articles in the top 10 [Table 2].^[1]

Authorship, institution, nation, and journals

Given the authorship of the *in vitro* arm of our analysis, we gather that early biomechanical analysis of ACR was greatly influenced by Uribe of Barrow Neurological Institute and his colleagues. Moreover, a key finding of our analysis is that the first clinical experience of ACR published in any form was the adjunct clinical cases supplied in the cadaveric study by Deukmedjian *et al.*^[7] that depicted preliminary *in vitro* evidence of SL correction in humans.

Uribe also offered significant contributions to the clinical arm of our study, having been involved in the authorship of four of the seven *in vivo* studies included in our top-ten list. In fact, we found that historically one of the largest institutional contributors to the study of ACR is the University of South Florida largely because of Uribe’s appointment there; this is also true in a narrower sense of Barrow Neurological Institute’s contribution to the domain of ACR research [Figures 2 and 4].

Overwhelmingly, the scholars and institutions that contributed to the top-ten most-cited articles on ACR were located in the United States [Figure 3], signifying the nation’s disproportionately large contribution to the study of ACR. Despite this, a plurality of the research [4/10 articles, Figure 5] of analyzed studies were actually published in journals located in Europe (*European Spine Journal*).

Limitations

One key problem with the implementation of our study is the fact that its analysis will alter future iterations of our work due to the citation of each of these works that occurred in this article. This may slightly affect total citations, citation rate, and potentially even peak citation year in future analysis. Moreover, due to the lack of centralized methodology, or systematization, our analysis does not offer comparative power between studies

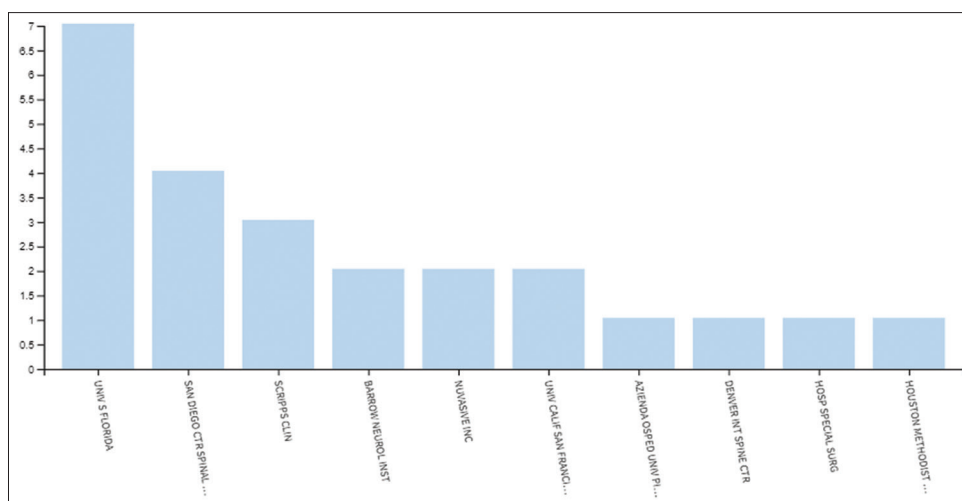


Figure 4: Top contributing institutions to the top-ten most-cited articles

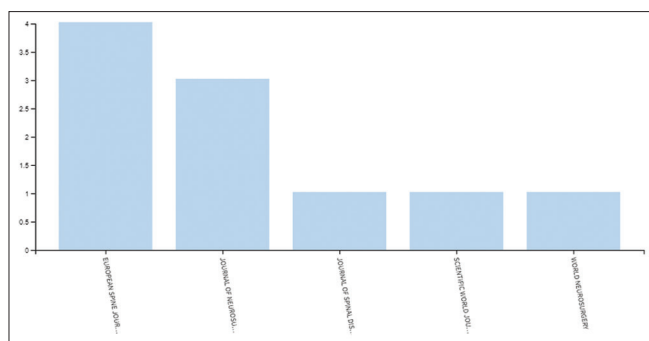


Figure 5: Journals of the top-ten most-cited articles

to inform scholars on this topic beyond our subjective appraisal of these articles. Finally, articles were acquired from a keyword search of the Reuters Web of Knowledge and are therefore subject to how completely this search adequately captures existing ACR literature.

CONCLUSIONS

Since its first technical description in 2012 by Uribe *et al.*,^[1] ACR has enjoyed significant attention, with the top-ten most-cited articles being cited a total of 395 times as reported by the current analysis. However, the level of evidence of these articles rarely rises above retrospective outcome analysis or *in vitro* biomechanical studies. Therefore, attention to lateral ACR is growing, but higher-level analyses with robust control groups, larger sample sizes, and subsequent replication are required to fully assess the sagittal correction capacity and safety of the procedure as a tool in the spine surgeon's armament for treating ASD.

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Conflicts of interest

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