Original Article

Anterior cervical hybrid constructs reduce superior adjacent segment burden compared to multilevel anterior cervical discectomy and fusion

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Background: Traditional surgical treatment for symptomatic cervical degenerative disc disease is anterior cervical discectomy and fusion (ACDF), yet the increased risk of adjacent segment degeneration (ASD) requiring additional surgery exists and may result in limiting long-term surgical success when it occurs. Disc arthroplasty can preserve or restore physiologic range of motion (ROM), decreasing adjacent level stress and subsequent surgery. For patients with multilevel pathology requiring at least a 1-level fusion, interest is growing in anterior cervical hybrid (ACH) surgery as a partial motion-preserving procedure to decrease the adjacent level burden. This radiographic study compares postoperative superior adjacent segment motion between ACH and ACDF. Secondarily, total global motion, construct motion, inferior adjacent segment motion, and sagittal alignment parameters were compared.

Methods: This is a single-center, multi-surgeon, retrospective cohort study of 2- and 3-level ACH and ACDF cases between 2013 and 2021. Degrees of motion were analyzed on flexion/extension views using Cobb angles to measure global (C2–C7) construct and adjacent segment lordosis. Neutral lateral X-rays were analyzed for alignment parameters, including global lordosis, cervical sagittal vertical axis (cSVA), and T1 slope (T1S). Differences were determined by independent t-test and Fisher's exact test.

Results: Of 100 patients, 38% were 2-level cases (47% ACH, 53% ACDF) and 62% were 3-level cases: (52% ACH, 48% ACDF). Postoperatively, superior adjacent segment motion increased with ACDF and decreased with ACH (–1.3°±5.3° ACH, 1.6°±4.6° ACDF, P=0.005). Postoperatively, the ACH group had greater ROM across the construct (16.3°±8.7° ACH, 4.7°±3.3° ACDF, P<0.001) and total global ROM (38.0°±12.8° ACH, 28.0°±11.1° ACDF, P<0.001). ACH resulted in a significant reduction of motion loss across the construct (–10.0°±11.7° ACH, –18.1°±10.8° ACDF, P<0.001). Postoperative alignment restoration was similar between both cohorts (–2.61°±8.36° ACH, 0.04°±12.24° ACDF, P=0.21).

Conclusions: Compared to ACDF, hybrid constructs partially preserved motion across operative levels and had greater postoperative global ROM without increasing superior adjacent segment mobility or sacrificing alignment restoration. This supports the consideration of ACH in patients with multilevel degenerative cervical pathology requiring at least a 1-level fusion and suggests a propensity for long-term success by reducing the superior adjacent segment burden.

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Introduction

A staggering 3.2 million people suffer from cervical degenerative disc disease in the United States annually (1). The standard surgical treatment is anterior cervical discectomy and fusion (ACDF) for cases refractory to nonoperative measures. Patients with multilevel pathology undergoing an all-fusion procedure have an increased risk of developing adjacent segment degeneration (ASD), which can result in a domino effect requiring additional surgery and limit long-term surgical success (2,3). Anterior cervical disc replacement (ACDR) has become an alternative treatment of cervical disc disease that has been shown to provide the same therapeutic benefit as ACDF while maintaining or restoring physiologic range of motion (ROM) at the treated level(s), thereby decreasing the burden on adjacent segments. As a result, the incidence of ASD and the need for additional surgery is reduced (4-7).

Combining ACDF and ACDR in a "hybrid" surgery [anterior cervical hybrid (ACH)] is a relatively novel technique for multilevel disc degeneration. This allows the surgeon to customize treatment on a per-level basis. ACH has been shown to be a safe and effective surgical treatment in early case reports and studies (8-10). An expected benefit of this partial motion-preserving surgery is reduced stress transfer to the superior adjacent segment as compared to a motion-sacrificing fusion-only construct (11,12). There are early studies that compare radiographic parameters between ACDF and ACH constructs, yet further information is needed to demonstrate consistency (13-17). The primary purpose of this study was to compare postoperative superior adjacent segment motion between ACH and multilevel ACDF surgeries. Secondary aims included comparison of construct motion, global motion, inferior adjacent segment motion, and cervical sagittal alignment parameters between ACDF and ACH. We present this article in accordance with the STROBE reporting checklist (available at https://jss.amegroups.com/article/view/10.21037/jss-23-135/rc).

Highlight box

Key findings

- Anterior cervical hybrid (ACH) surgery reduced superior adjacent segment motion while the traditional anterior cervical discectomy and fusion (ACDF) increased it postoperatively.
- There was no difference in postoperative alignment restoration between ACH and ACDF.

What is known and what is new?

- It is established that ACDF is a motion-sacrificing procedure with increased risk of adjacent segment disease (ASD), arthroplasty is a motion-preserving procedure with less risk of ASD, and studies are emerging to describe radiographic results of hybrid surgery.
- ACH is a partial motion-preserving surgery with greater potential for long-term success compared to ACDF by reducing the adjacent level burden.

What is the implication, and what should change now?

- The clinical benefit of partially preserving the construct motion coupled with a return to physiologic superior adjacent segment motion after ACH surgery is expected to be greater than when sacrificing construct motion and developing compensatory adjacent segment hypermobility after ACDF.
- ACH surgery should be considered for multilevel cervical cases when at least 1-level of fusion is necessary.

Methods

Study design and patient selection

This is a retrospective cohort study of patients undergoing 2- or 3-level ACDF or hybrid surgery for degenerative pathologies at a multi-surgeon, single center between 2013 and 2021. Hybrid surgery was defined as any combination of ACDF and ACDR. Implant selection for fusion and arthroplasty was based on clinical judgment. The preoperative plan for all patients and all surgical levels included consideration for motion preservation. Arthroplasty implant-specific Food and Drug Administration (FDA) guidelines and insurance authorizations played the greatest role in which patients underwent a partial motion-preserving procedure versus a motion-sacrificing procedure. Adult patients (18 years

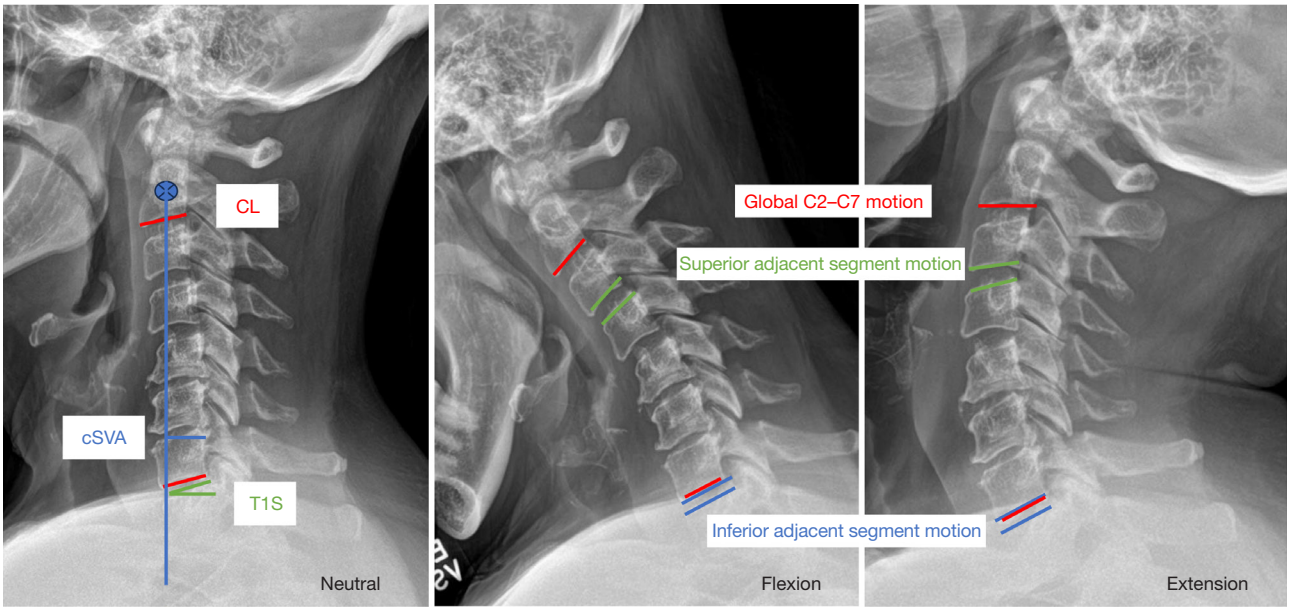

Figure 1 Example of measurements made on lateral X-rays, including CL, cSVA, T1S, and Cobb angles to measure global (C2–C7) lordosis, and adjacent segment lordosis (superior and inferior). CL, cervical lordosis; cSVA, cervical sagittal vertical axis; T1S, T1 slope.

or older) with a minimum of 6 months of follow-up and appropriate pre- and post-operative imaging (upright neutral lateral, flexion, and extension X-rays) were eligible for inclusion. Patients were excluded if the primary diagnosis was trauma, infection, or tumor, if imaging was insufficient to make appropriate X-ray measurements, if radiographs were taken outside of the institution, or if radiographs were flagged for patients who were unable to comply with the institution's standard ROM requirements during flexion and extension imaging. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by institutional board of Advarra (No. Pro00045821). Informed consent was taken from all the patients.

Data collection

Patient demographics including age, sex, body mass index (BMI), Charlson Comorbidity Index (CCI), nicotine use, and lowest T-score were collected from medical and operative records. Preoperative radiographs and postoperative radiographs at the most recent follow-up were reviewed and digitally measured by two fellowship-trained spine surgeons. *Figure 1* represents an example of these measurements. Cobb angles were measured on lateral flexion/extension cervical X-rays to determine lordosis globally (C2–C7), across the operative construct, and at the superior and inferior adjacent segmental levels. ROM was calculated as the sum of the absolute values of the Cobb angles in flexion and extension. Changes in motion after surgery were determined by calculating the difference between postoperative and preoperative motion parameters. Neutral lateral cervical X-rays were used for alignment measurements of C2–C7 global lordosis, cervical sagittal vertical axis (cSVA), and T1 slope (T1S). The formula used for calculating ideal cervical lordosis (CL) was ideal CL = T1S – 16.5°±2° as presented by Staub *et al.* in 2018 as a method of predicted normative CL (18). Sagittal alignment restoration was evaluated by calculating the difference between the actual postoperative CL and the preoperatively calculated ideal CL.

Statistical analysis

All analyses were performed using IBM SPSSv28.0 (Armonk, NY, USA). Values are represented as number and percentage or mean ± standard deviation. Differences between the ACH and ACDF cohorts were determined using the independent *t*-test for continuous variables and Fisher's exact test for categorical variables. Statistically significant P value was set at $P<0.05$.

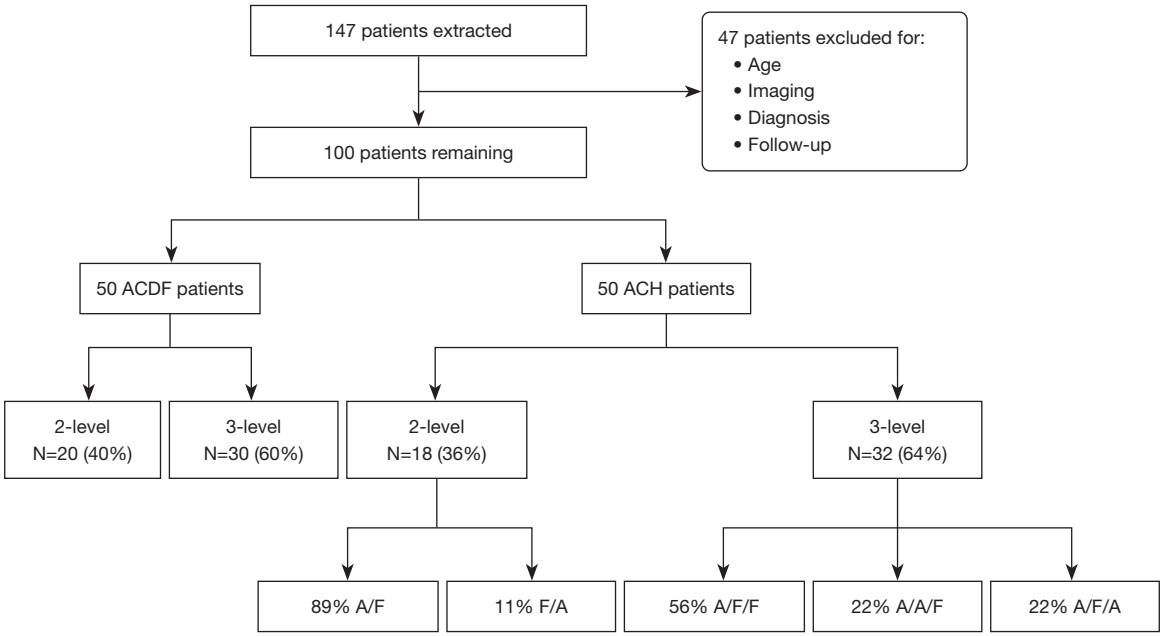

Figure 2 Flow diagram representing the cohort. ACDF, anterior cervical discectomy and fusion; ACH, anterior cervical hybrid; A, arthroplasty; F, fusion.

Results

Demographics and surgical details

Of 147 total patients, 100 patients remained after exclusion criteria were applied, with 50 patients in each cohort. *Figure 2* represents a flow diagram of the cohort. Mean age in years was within the same decade, but younger in the ACH cohort (50.6±8.7 years in ACH, 58.6±11.1 years in ACDF, P<0.001). The ACH cohort had a lower CCI (0.82±0.87 ACH, 1.73±1.40 ACDF, P<0.001). Mean follow-up time was 20.5±19.0 and 16.3±15.6 months in ACH and ACDF cohorts, respectively (P=0.23). The proportion of levels treated (2-level cases: 36% ACH, 40% ACDF; 3-level cases: 64% ACH, 60% ACDF) was similar between the groups, P=0.83 (*Table 1*).

Within the 2-level ACH cohort, hybrid constructs were as follows superiorly to inferiorly: 89% arthroplasty (A)/fusion (F) and 11% F/A. Within the 3-level ACH cohort, hybrid constructs were: 56% A/F/F, 22% A/A/F, and 22% A/F/A (*Figure 2*). Examples of these five different hybrid constructs are depicted in *Figures 3,4*. Within all 2- and 3-level hybrid constructs, the majority had arthroplasty superiorly (96%) and fusion inferiorly (82%).

Radiographic parameters: *motion*

The postoperative superior adjacent segment motion increased in the ACDF cohort and decreased in the ACH cohort (–1.3°±5.3° ACH, 1.6°±4.6° ACDF, P=0.005). The postoperative inferior adjacent segment motion was similarly increased in both groups (0.5°±5.2° ACH, 0.7°±4.2° ACDF, P=0.79). Total construct ROM was significantly greater in the ACH cohort (16.3°±8.7° ACH, 4.7°±3.3° ACDF, P<0.001), and the resultant loss of motion at the construct level was significantly less in the ACH cohort (–10.0°±11.7° ACH, –18.1°±10.8° ACDF, P<0.001). Total preoperative global motion (C2–C7) was higher in the ACH cohort (48.2°±12.7° ACH, 40.6°±12.7° ACDF, P=0.003), which remained higher postoperatively (38.0°±12.8° ACH, 28.0°±11.1° ACDF, P<0.001), and the loss of global motion was similar between groups (–10.2°±12.5° ACH, –12.6°±15.2° ACDF, P=0.40). Pre and postoperative ROM parameters are listed in *Table 2*.

Radiographic parameters: *alignment*

Pre- and post-operative cSVA did not differ significantly between the groups, therefore no significant change in cSVA postoperatively was found between the groups (1.3 mm ACH, –0.1 mm ACDF, P=0.34). Preoperative global lordosis and T1S were significantly lower in the ACH cohort compared to ACDFs (4.3° ACH, 10.5° ACDF, P=0.03 and 28.7° ACH, 32.8° ACDF, P=0.03, respectively).

Table 1 Patient characteristics

Characteristic	ACH value (n=50)	ACDF value (n=50)	P value
Male sex	23 [46]	17 [34]	0.30
Mean age (years)	50.6±8.7	58.6±11.1	<0.001
Mean CCI score	0.82±0.87	1.73±1.40	<0.001
Nicotine use	5 [10]	2 [4]	0.43
Mean BMI (kg/m^2)	28.6±4.8	29.2±5.7	0.53
Mean DEXA lowest T-score	−0.73±1.02	−1.02±1.36	0.23
Mean follow-up time (months)	20.5±19.0	16.3±15.6	0.23
Total levels			0.83
2	18 [36]	20 [40]	
3	32 [64]	30 [60]	

Values represent the number of patients [%] or mean ± SD. ACH, anterior cervical hybrid; ACDF, anterior cervical discectomy and fusion; CCI, Charlson Comorbidity Index; BMI, body mass index; DEXA, dual-energy X-ray absorptiometry; SD, standard deviation.

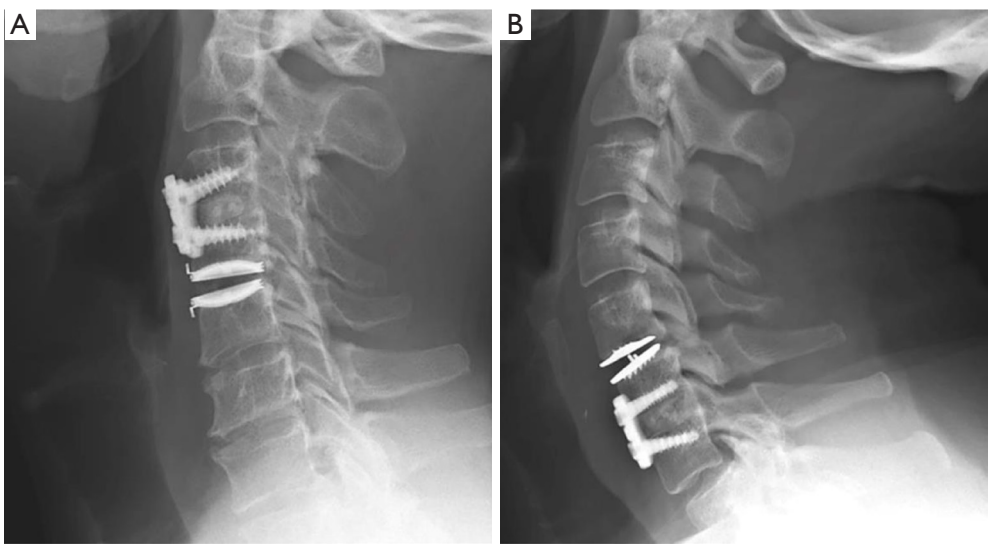

Figure 3 Lateral X-rays showing examples of 2-level hybrid constructs in this cohort: (A) fusion/arthroplasty and (B) arthroplasty/fusion.

Postoperative global lordosis and T1S remained lower in the ACH cohort (9.6° ACH, 16.3° ACDF, P=0.004 and 29.2° ACH, 33.5 ACDF, P=0.009, respectively). The two groups were similar in postoperative alignment restoration (−2.6°±8.4° ACH, 0.04°±12.2° ACDF, P=0.21). Pre and postoperative alignment parameters are listed in *Table 3*.

Discussion

The results show partial motion-preservation of the construct and globally without increased motion of the superior adjacent segment for ACH surgeries when compared to multilevel ACDFs in this study. Total construct motion was 16.3° on average in the hybrid cohort compared to 4.7° in the ACDF cohort contributing to a greater postoperative global ROM of 38.0° in the ACH cohort compared to 28.0° in the ACDF cohort. Clinical efficacy and safety of ACH surgery have been well established in the current literature (9,19-24). However, several reviews and meta-analyses have found that data specifically analyzing

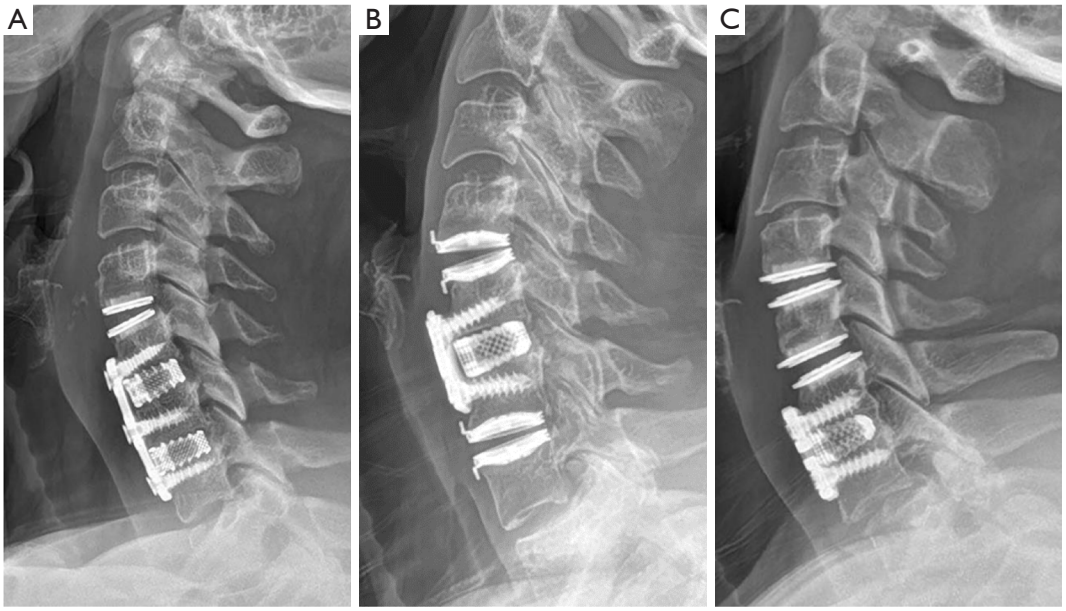

Figure 4 Lateral X-rays showing examples of 3-level hybrid constructs in this cohort: (A) arthroplasty/fusion/fusion, (B) arthroplasty/fusion/arthroplasty, and (C) arthroplasty/arthroplasty/fusion.

Table 2 Range of motion parameters

Motion parameters	ACH value	ACDF value	P value
Preoperative motion (°)			
Total construct motion	26.3±10.8	22.7±10.4	0.09
Total global motion	48.2±12.7	40.6±12.7	0.003
Total superior adjacent segment motion	10.8±4.9	8.0±4.1	0.002
Total inferior adjacent segment motion	5.7±4.1	5.8±3.5	0.83
Postoperative (≥6 months) motion (°)			
Total construct motion	16.3±8.7	4.7±3.3	<0.001
Total global motion	38.0±12.8	28.0±11.1	<0.001
Total superior adjacent segment motion	9.6±5.0	9.6±3.8	0.98
Total inferior adjacent segment motion	6.1±4.4	6.5±4.2	0.64
Difference between post and preoperative motion (°)			
Total construct	−10.0±11.7	−18.1±10.8	<0.001
Total global	−10.2±12.5	−12.6±15.2	0.40
Total superior adjacent segment	−1.3±5.3	1.6±4.6	0.005
Total inferior adjacent segment	0.5±5.2	0.7±4.2	0.79

Values represent the mean ± SD. ACH, anterior cervical hybrid; ACDF, anterior cervical discectomy and fusion; SD, standard deviation.

Table 3 Sagittal alignment parameters

Sagittal alignment parameters	ACH value	ACDF value	P value
Preoperative			
Ideal cervical lordosis (°)*	12.2±8.1	16.3±10.5	0.03
Global lordosis (°)	4.3±11.9	10.5±16.2	0.03
T1 slope (°)	28.7±8.1	32.8±10.5	0.03
cSVA (mm)	28.0±10.6	29.2±10.7	0.57
Postoperative			
Global lordosis (°)	9.6±9.1	16.3±13.4	0.004
T1 slope (°)	29.2±7.1	33.5±9.1	0.009
cSVA (mm)	29.3±10.0	29.1±10.0	0.92
Sagittal alignment restoration (°)**	−2.6±8.4	0.04±12.2	0.21
Change in cSVA (mm)	1.3±7.9	−0.1±6.6	0.34

Values represent the mean ± SD. *, ideal cervical lordosis = T1 slope − 16.5°±2°; **, alignment restoration = postoperative global lordosis minus ideal cervical lordosis. ACH, anterior cervical hybrid; ACDF, anterior cervical discectomy and fusion; cSVA, cervical sagittal vertical axis; mm, millimeters.

motion kinematics in ACH surgery as compared to matched ACDF counterparts is limited by small sample sizes (13-17). This study provides additional clinical data supporting the use of ACH surgery for patients with multilevel cervical pathology.

While ACDF is the standard treatment for symptomatic cervical degenerative disc disease, there is a risk of ASD. A recent meta-analysis of 19 studies by Toci *et al.* found a significant cumulative ASD rate of 19.7% following ACDF compared to 14.4% from ACDR (25). Hypermobility at adjacent segments to fusion-only constructs contributes to ASD, and this effect is reproducible when comparing ACDF to hybrid surgery. An early study by Lee *et al.* reported significant increases in ASD when comparing 2-level fusion-only constructs to 2-level hybrid constructs (26). Similarly, in Xiong *et al.*'s retrospective study comparing ACDF to ACH, superior adjacent segment mobility was significantly increased at six years in their ACDF group (10.07°±4.82° preoperative and 13.26°±5.95° at follow-up, P<0.05) compared to a decrease in their hybrid group (11.34°±6.49° preoperative and 9.26°±6.07° at follow-up, P<0.05) (27). Huang *et al.* compared 3-level ACH with ACDF and found that the superior adjacent segment ROM was significantly higher in the ACDF group (28). Similar findings have been reported in other early studies comparing hybrid surgery to matched ACDF counterparts in patients with 2- and 3-level cervical degenerative disc disease (DDD) (29-31).

In this study, superior adjacent segment motion increased postoperatively in the ACDF cohort while hybrids had a decrease in this parameter (P=0.005). This suggests that the combination of arthroplasty with fusion may reduce the potential risk of ASD and subsequent re-operation. The decrease in superior adjacent segment mobility after ACH might represent the return of that level's physiologic motion; or in other words, after the pathology is treated and motion is partially preserved, the superior adjacent level burden lessens from its previous state of overcompensation. There was no significant difference between pre- and post-operative total inferior adjacent segment motion for either the ACH or ACDF cohort in our study. This finding was expected given the majority (82%) of our ACH cohort were fused inferiorly, adjacent to the inferior segment.

An advantage of hybrid surgery over the traditional fusion-only approach is the partial preservation of physiologic motion. Patients undergoing multilevel cervical fusion have a restricted ROM, and this can be more problematic for younger or more active patients. While hybrid constructs always contain at least one level of fusion, combining ACDF with a motion-preserving arthroplasty has been shown to effectively partially preserve physiologic global ROM (31-33). ACH patients in our study had an average of 48.2° of global motion preoperatively and 38.0° postoperatively. This outperformed our ACDF cohort clinically, which had a mean preoperative global ROM of

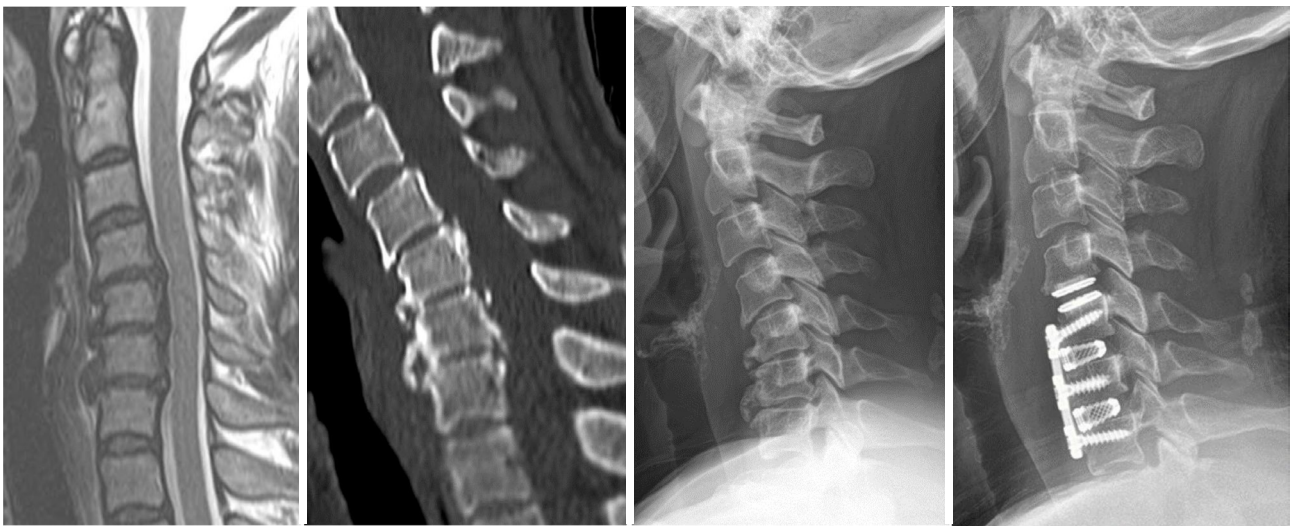

Figure 5 Case example demonstrating 3-level degenerative changes and kyphosis treated with ACH (arthroplasty/fusion/fusion). MRI, magnetic resonance imaging; CT, computed tomography; ACH, anterior cervical hybrid.

40.6° and 28.0° postoperatively, though the overall change did not reach statistical significance between groups.

Ji *et al.* conducted a study comparing 2-level fusions with 2-level hybrid surgeries and reported that preoperative global ROM was 51.4° compared to 44.9° at 2 years after ACDF and preoperative global ROM was 54.0° and 54.1° at 2 years after ACH. This difference was statistically significant at the 2- and 3-year follow-up points but not at 5 years postoperatively (34). A recent meta-analysis by Zhang *et al.* found statistically significant preservation of C2–C7 ROM in ACH constructs compared to ACDF constructs (17).

In our study, although the postoperative global motion was significantly greater in the ACH cohort, the total loss of global motion after surgery was not significantly different between groups. This may be explained by the increase in the superior adjacent segment motion seen in the ACDF group countering the decrease in the superior adjacent segment motion in the ACH group. The clinical benefit of partially preserving the construct ROM coupled with a return (decrease) to a more physiologic superior adjacent segment motion is expected to be greater than sacrificing motion at the level of the construct and developing compensatory hypermobility at the superior adjacent segment.

Both ACH and ACDF improved cervical alignment parameters. Preoperative global lordosis improved from 4.3° to 9.6° in the ACH cohort and 10.5° to 16.3° in the ACDF cohort. To better understand alignment, ideal CL was calculated based on preoperative parameters, which differed significantly between cohorts (P=0.03). The global lordosis achieved after surgery was compared to the ideal lordosis calculated before surgery to ascertain the degree of alignment restoration, which was not different between the groups, suggesting that ACH and ACDF similarly restore alignment. In addition, the change in cSVA was small in each cohort and the comparison between cohorts did not reach significance, demonstrating that both constructs produce similar sagittal alignment results. *Figures 5,6* are ACH case examples where preoperative cervical kyphosis is present.

A study by Wang *et al.* found increases in CL following hybrid surgery, ACDF, and ACDR, however, these results were not significantly different between the groups (35). These are similar to the findings reported by Ding *et al.*'s study, which reported no statistical difference in CL between ACH and ACDF (32). A recent radiographic study by Chen *et al.* comparing 3-level ACH and ACDF demonstrated that the fusion group had a significant decrease in CL and segmental angles at 1 year compared to the hybrid groups (36). These and other studies suggest that ACH surgery is at least as effective as ACDF surgery in restoring CL (37).

This study has several limitations. A relatively small sample size of patients undergoing elective surgery at a single institution may limit generalizability to a

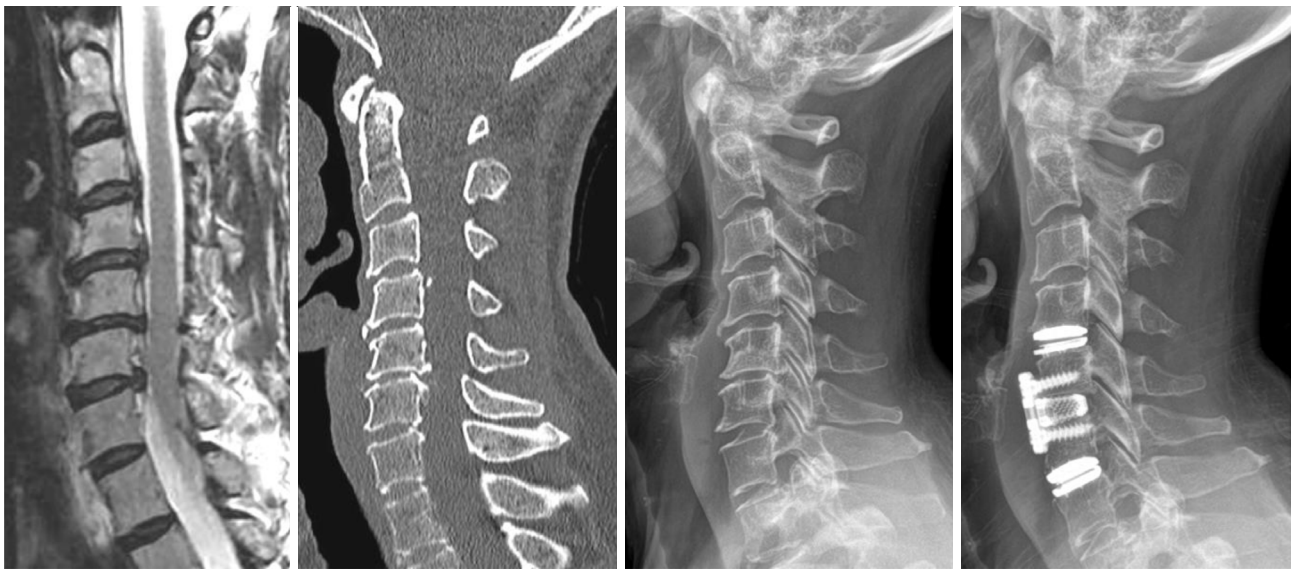

Figure 6 Case example demonstrating 3-level degenerative changes and kyphosis treated with ACH (arthroplasty/fusion/arthroplasty). MRI, magnetic resonance imaging; CT, computed tomography; ACH, anterior cervical hybrid.

more heterogeneous population and may introduce bias. Procedural selection bias is a consideration in this retrospective study. The determination between ACH and ACDF in this study remained uniform. The preoperative plan for all patients and all surgical levels included consideration for motion preservation. Arthroplasty implant-specific FDA guidelines and insurance authorizations played the greatest role in which patients underwent a partial motion-preserving procedure versus a motion-sacrificing procedure. While our overall mean patient age was 55 years, the ACH cohort was somewhat younger than the ACDF cohort. This could potentially act as a confounder, as younger patients may naturally restore motion better than older patients, however, mean ages within each surgical group remained in the fifth decade. The arthroplasty implant-specific FDA guidelines used to determine eligibility for motion-preservation more often aligned with the anatomy of younger patients, which is indicative of real-world cases. This retrospective study focused solely on kinematic parameters using radiographs and does not specifically examine complication rates or patient-reported outcomes. Future studies comparing surgical outcomes between ACH and ACDF could include the evaluation of any revision surgery secondary to complications such as heterotopic ossification or osteolysis in disc replacement levels, pain from motion preservation in disc replacement levels, pseudoarthrosis in fused levels, or adjacent segment surgery.

Conclusions

ACH surgery is an effective technique for the treatment of 2- and 3-level cervical degenerative disc disease when at least one level of fusion is necessary. This partial motion-preserving surgery has the potential to restore superior adjacent segment motion to function more physiologically compared to the motion-sacrificing all-fusion approach without limiting the alignment restoration potential. The reduction in superior adjacent segment motion after hybrid surgery in this study favors the potential for long-term success of partial motion preservation with regards to adjacent level burden.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://jss.amegroups.com/article/view/10.21037/jss-23-135/rc

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jss.amegroups.com/article/view/10.21037/jss-23-135/coif). L.D.O. and R.T.R. received institutional research support from Medtronic and Innovasis. C.R.G. serves on an advisory board for Stryker/K2M, Medtronic, and Augmedics. C.R.G. reports royalties and consulting fees from Stryker/K2M and Medtronic; institutional educational research support from Medtronic; owns stock in Audmedics and NSite. E.J. reports consulting fees from Stryker, Medtronic, and Innovasis. C.M.H. reports personal fees from Medtronic, Globus Medical, Spineart, and Innovasis. 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 board of Advarra (No. Pro00045821). Informed consent was taken from all the patients.

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