BMC Surgery

SYSTEMATIC REVIEW

Open Access

Evaluating the effectiveness of the transcorporeal approach in minimally invasive spine surgery for cervical spinal disease: a comprehensive review and technical insights

Yanting Liu[1†], Siravich Suvithayasiri[2,3†], Facundo Van Isseldyk[4], Vit Kotheeranurak[5], Khanathip Jitpakdee[6], Kyung-Chul Choi[7], Gun Choi[8], Junseok Bae[9] and Jin-Sung Kim[1*]

Abstract

Background The evolution of minimally invasive spine surgery, propelled by microscopy and endoscopy techniques, has reshaped the landscape of spinal interventions. The anterior approach to the cervical spine is widely recognized for its reproducibility and effectiveness in treating pathologies leading to radiculopathy or myelopathy. Apart from the traditional transdiscal approach, this study delves into the anterior transcorporeal approach, a minimally invasive technique, exploring its applicability in various cervical spinal pathologies.

Purpose The objective is to comprehensively illustrate the anterior transcorporeal approach, exploring its historical development, biomechanical underpinnings, technical nuances, and clinical applications in managing cervical spine disorders.

Methods We conducted a comprehensive review using PubMed, Embase, Cochrane Library, and Web of Science, adhering to PRISMA guidelines. The search was focused on the minimally invasive anterior transcorporeal approach for cervical pathologies, with an emphasis on evaluating the methodological evolution, technical execution, and clinical outcomes across diverse studies.

Results The review identified a significant body of literature supporting the efficacy of the minimally invasive anterior transcorporeal approach. Over the past two decades, this approach has demonstrated encouraging clinical outcomes, suggesting its potential as an alternative strategy for specific cervical spine diseases. The evolution of this technique is tightly linked to the advancements in medical equipment and the innovative endeavors of surgical pioneers.

Conclusions The anterior transcorporeal approach marks a milestone in minimally invasive cervical spine surgery. Its development reflects ongoing efforts to refine surgical techniques for better patient outcomes. While offering a promising alternative for treating certain cervical spine conditions, the approach demands precise case selection

†Yanting Liu and Siravich Suvithayasiri will be the co-first author.

*Correspondence:
Jin-Sung Kim
mdlukekim@gmail.com; md1david@catholic.ac.kr
Full list of author information is available at the end of the article

and is influenced by the rapid progression of medical technology. Future research and technological advancements are expected to further enhance the efficacy and safety of this approach, potentially expanding its indications in spinal surgery.

Keywords Spine Injuries and Disorders, Cervical, Endoscopy, Microscopy, Diskectomy, Transcorporeal

Introduction

An anterior approach to the cervical spine is commonly used to treat cervical-related pathologies leading to radiculopathy or myelopathy [1, 2]. It is a safe and effective approach as it creates anatomical dissection through the anterolateral neck fascial layers, which can preserve anatomical structures and ultimately lessen the collateral damage to the surrounding tissue. The cervical anterior approach is usually combined with discectomy, fusion, or corpectomy procedures, which may decrease the integrity of the natural structures, increase mechanical stress, and eventually accelerate the degeneration of the adjacent segments [3]. Motion-preservation strategies, such as cervical disc replacement, have been an alternative in recent years. However, it is often associated with unintended spontaneous fusion and heterotopic ossification, which will still hinder the primary goal of this motion-preserving strategy [4, 5].

In recent years, minimally invasive spine surgery (MISS) has become more prevalent, with the steady development of microscopy and endoscopy instruments and the adoption of the techniques along the way [6]. The use of MISS in the lumbar spine has gradually entered a mature era. Therefore, the focus of its research and new techniques has slowly shifted to the cervical spine. Conventionally, the most reported technique is the anterior transdiscal approach (ATd) [7, 8]. However, this technique could lead to excessive dissection of the residual disc and decrease the load capacity of the nucleus pulpous, which, as a result, generates compensatory mechanical changes and more load transfer to the adjacent segments [9–12]. The Anterior Microscopic Transcorporeal Approach (AMTc) and the Anterior Full-Endoscopic Transcorporeal Approach (AETc) have been developed as innovative surgical strategies to circumvent associated complications, such as inadvertent intervertebral disc damage and degeneration while preserving the mechanical integrity of the vertebral body.

The present review adopts a comprehensive review framework to systematically explore the breadth of existing literature on the transcorporeal approach in minimally invasive cervical spine surgery. This methodology allows for an in-depth examination of key concepts, technical nuances, biomechanical underpinnings, and clinical applications of these approaches. In addition to evaluating the existing evidence, we integrate technical insights from our team's experience with the transcorporeal technique. Our comprehensive review critically assesses the literature and incorporates real-world technical proficiency. This approach enables a more focused and thorough understanding of the transcorporeal approach, providing both a synthesis of the current evidence and expert insights into its clinical application.

Materials and methods

Search strategy and eligibility criteria

Two authors (Y.T. and S.S.) designed and performed a computerized bibliographic search strategy. The present study conducted the review based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Fig. 1) [13]. The protocol for our review has been pre-registered with PROSPERO under the Registration Number CRD42023489694. The electronic databases PubMed, Embase, Cochrane Library, and Web of Science were searched for literature regarding the ATc for cervical pathologies. All the above databases were searched for relevant studies from inception to January 2024. The search strategy was used alone or in a combination of MeSH terms and keywords. For example, the search strategy for PubMed: (Spine[MeSH Terms] OR Spinal Cord Diseases[MeSH Terms]) AND cervical[Title/Abstract] AND (microscop* OR endoscop* OR arthroscop* OR video-assisted surgery OR minimally invasive surgery). If no MeSH search function was available, the search "Title/Abstract" or "Keywords" were transferred. According to our estimates, statistical analyses could not be satisfactorily performed to conduct a meta-analysis due to the low number of publications regarding this topic and the probable high chances of observing high heterogeneity between studies. Therefore, we conducted a review summarizing reported aspects, including a brief historical review, biomechanical analysis, technical description, and clinical trials.

There are two stages in our study. First, two reviewers (Y.T. and F.V.) independently screened the titles or abstracts obtained from the searched databases. Then, full-text screening was performed on the included screened papers. The reference lists of the included studies were hand-searched for other relevant studies meeting the inclusion criteria that may have been missed. Then, they examined the included studies, proofread them, and extracted the relevant demographic data. Each

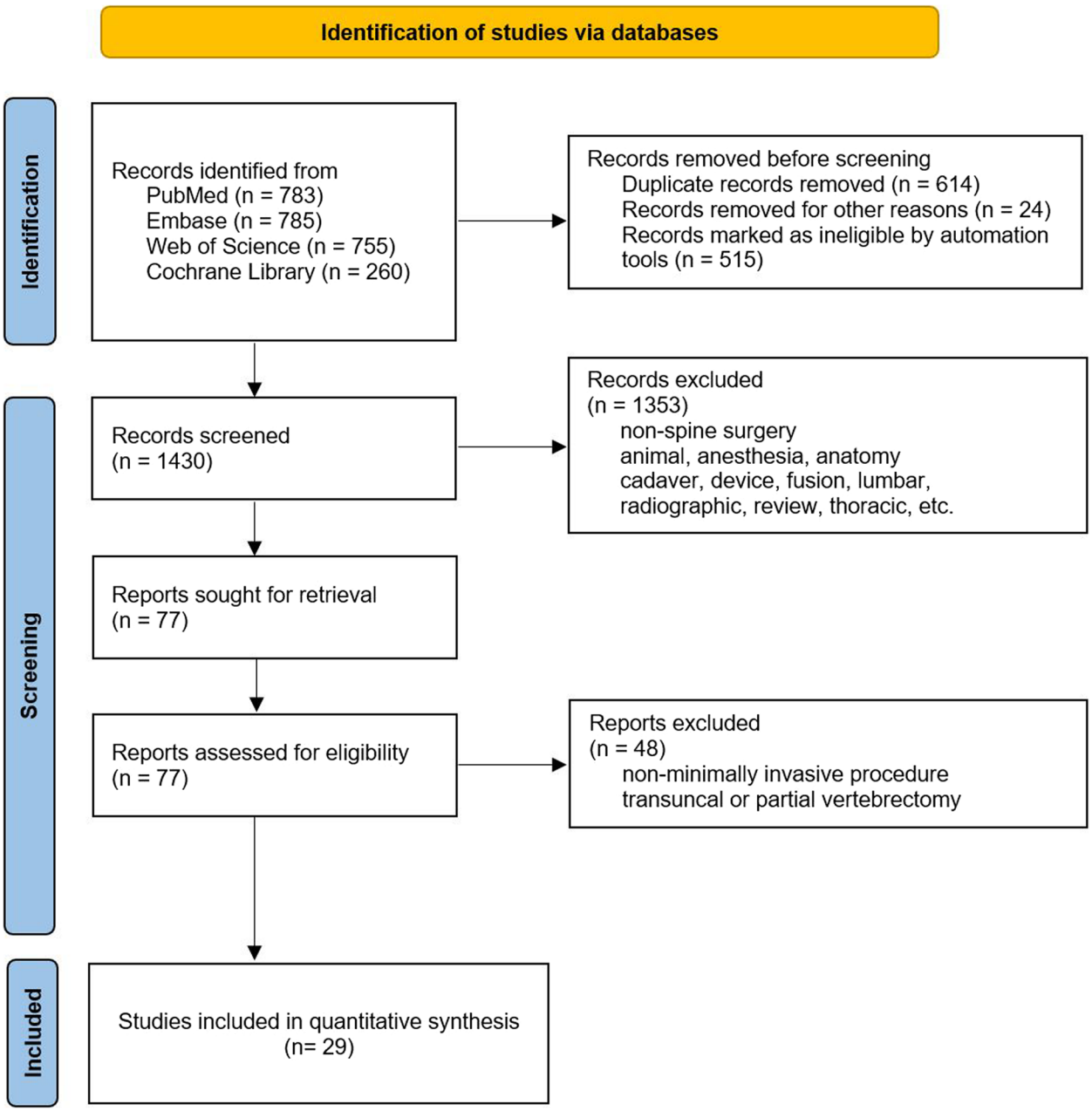

Fig. 1 The flowchart diagram illustrates the included articles included in the review

of them also did verification to minimize investigator bias. Demographic data from the included studies were collected using Microsoft Excel 2019 (Microsoft, WA). Any discrepancies between the two researchers were discussed. If a consensus were not achieved, it would be settled by negotiation with a third senior professor (J.S.K.) to reach an agreement. Only human studies written in the English language are screened. All types of studies, including case reports and case series, with any follow-up time frame, are enrolled.

Risk of bias assessment

In our study, we choose Joanna Briggs Institute (JBI) critical appraisal tools to make a detailed and unbiased analysis of the selected studies, which are comprehensive instruments designed to assess the methodological quality and risk of bias in various types of research studies [73]. We utilized a set of questions, as prescribed by the JBI, each scrutinizing a specific aspect of study design and execution. For cohort studies, the JBI Critical Appraisal Checklist includes assessments of

group similarity, exposure measurement, confounding factors, outcome measurement, follow-up completeness, and the appropriateness of statistical analysis. In case reports, the JBI checklist focuses on details like patient demographics, history timeline, diagnostic methods, intervention descriptions, and the reporting of adverse events. For case series, the tool evaluates criteria for inclusion, consistency in condition measurement, validity of condition identification methods, participant demographics, clinical information reporting, outcome follow-up results, and the appropriateness of statistical analysis.

To enhance the precision of our assessment, we introduced differentiated weightings for each question, recognizing that certain aspects of study design are more critical in determining bias. The conventional binary responses ('yes,' 'no,' and 'unclear') were replaced with a more granular scoring scale, allowing for partial credits and reflecting varying degrees of compliance with quality standards. The risk of bias was then categorized based on a revised set of percentage thresholds: high risk for scores up to 49%, moderate risk for scores between 50 and 69%, and low risk for scores above 70%. Due to the relatively lower standard of evidence in spine surgery reports compared to established criteria, we have introduced a modified assessment result, denoted as "yes*." This designation acknowledges universal reporting forms that, while not fully adhering to the original guidebook's reporting standards, still align with the current average in spine science reporting. This adjustment allows for a more inclusive and realistic evaluation of spine surgery reports within their specific scientific context. To ensure consistency and objectivity in our assessments, two reviewers (Y.T. and S.S.) underwent training and focused on the application of these revised criteria.

Definition of the transcorporeal (ATc) approach

There is still no clear definition of the ATc approach in the literature. From our point of view, the concept is to reach the ventral side of the spinal canal by using the route through the vertebral body. However, the remaining integrity of the vertebral body also needs to be sufficient to support the cervical spine, which must be balanced. We believe the ATc approach is one of the minimally invasive procedures with no excessive resection of the vertebral bodies or violation of the medial boundary of the transverse foramen [14–17]. As a result, we also did not consider the transuncal or partial vertebrectomy as an ATc approach and did not include them in our study. An example of the Anterior Full-Endoscopic Transcorporeal Approach (AETc), showing the optimal trajectories for addressing cervical spine lesions at various levels and positions within the spinal canal, is presented in Fig. 2.

Definition of the transcorporeal (ATc) approach

We conducted statistical analyses using Review Manager (version 5.3). Additionally, single-arm meta-analyses were carried out to evaluate changes in outcomes, utilizing Stata software (version 17.0). For categorical variables, odds ratios (OR) were used to summarize the data, while mean differences (MDs) were applied for continuous variables. A significance level of $P < 0.05$ was adopted. To assess potential heterogeneity between the studies, we employed the I^2 statistic. The heterogeneity was classified as follows: no heterogeneity (I^2: 0%–25%), low (I^2:

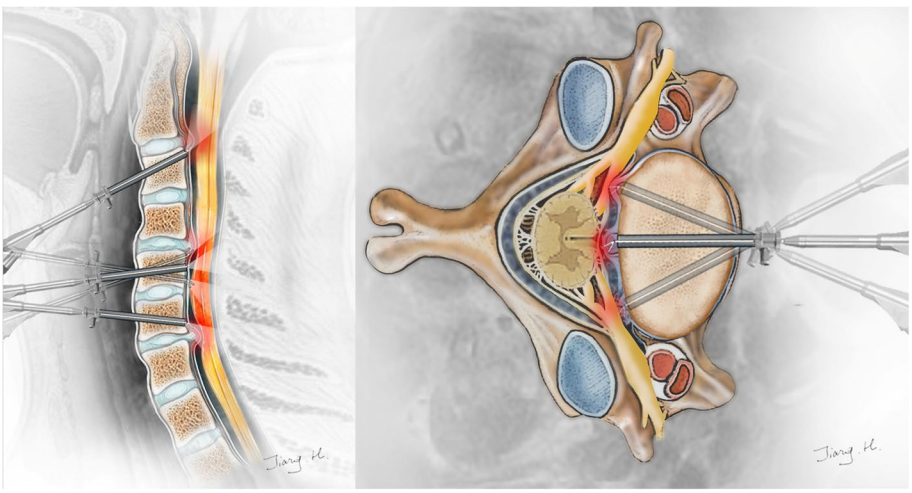

Fig. 2 Illustrations show optimal trajectories for the Anterior Full-Endoscopic Transcorporeal Approach (AETc) in treating cervical spine lesions at various levels and positions of the spinal canal

25.1%–50%), moderate (I^2: 50.1%–75%), and high (I^2: 75.1%–100%). We also performed a subgroup analysis based on different time points (months) accordingly. Forest plots from the single-arm meta-analyses were used to visually represent the results of individual studies alongside the combined estimated effect sizes.

Results

Demographics of studies on transcorporeal approaches in spinal surgery

This comprehensive review summarized 29 studies focusing on the transcoporeal approach in spinal surgery, spanning from 2000 to 2023 (Table 1). These studies, predominantly case series and reports, with a significant concentration in Asian countries, particularly Japan, Korea, and China. Clinical assessments varied but often included the Visual Analog Scale (VAS), Japanese Orthopaedic Association (JOA) score, and other functional and radiographic measurements. The ages of the patients range from 33 to 68 years, with the average patient age generally falling in the late 40 s to early 50 s. This indicates that the majority of these surgical cases pertain to middle-aged adults. Most studies focus on patients diagnosed with HNP, with many cases also reporting concurrent osteophytes, stenosis, and degenerative disc disease. The most commonly treated cervical region are between C2 and C7, with several studies involving multi-level surgeries that C3-C7 being the most frequently operated levels. The surgical techniques reported across the studies include both microdiscectomy and full-endoscopic technique. These procedures are typically performed to alleviate the symptoms associated with HNP, stenosis, and osteophyte formation, which can lead to severe pain and neurological impairment.

The duration of operation ranging from 42.8 min to 204.8 min for 1 to 4 levels separately. The average operation time for each level is approximately 40.53 ± 19.44 min. Some studies reporting a short follow-up of 3 months, while others track patient outcomes for as long as 13 years. The length of stay in the hospital ranges from 1 to 7 days, with some cases reporting longer hospital stays for patients who experienced complications. Several adverse events were reported, though they were relatively infrequent. Synthesis complications including transient swallowing difficulty, numbness or tingling, CSF leaks, ASD, mediastinal effusion, endplate collapse, or laryngeal spasms. The majority of these complications were minor and transient, resolving without long-term consequences for the patients. In some cases, however, more serious events like adjacent segment disease required additional intervention or prolonged follow-up.

Risk of bias of anterior transcorporeal approach studies

In assessing the results from the JBI Critical Appraisal Checklist across different study types, the data reveals a wide range of methodological strengths and weaknesses (Table 2). The single cohort study by Ren et al. [18] exhibited a high risk of bias with only 45.5% positive responses, mainly due to uncertainties in group similarities, exposure measurements, and strategies for confounding factors. The case series showed a broad spectrum of compliance, with Ma [19] and Ye et al. [20] demonstrates the highest methodological rigor, contrasting sharply with Nakai et al. [21] at the lower end, primarily due to inadequate criteria for participant inclusion and inconsistent reporting. Case reports generally fared better, predominantly falling into moderate to low-risk categories.

Surgical outcomes meta-analysis of the anterior transcorporeal approach

The forest plot (supplement file) illustrates the synthesis analysis the JOA score to evaluate the surgical outcomes at 6 and 12 months postoperatively from seven studies. As depicted, the pooled MD in JOA scores from baseline showed a significant improvement at both time points. At 6 months, the pooled analysis from four studies demonstrated a mean improvement of 6.32 points (95% CI: 5.61 to 7.03) in the JOA score, reflecting the early positive impact of the endoscopic approach on patient outcomes. At 12 months, the pooled mean difference was 5.87 points (95% CI: 5.38 to 6.36), indicating that the improvements were sustained over time. Overall, the combined effect size across both time points showed an average improvement of 6.01 points (95% CI: 5.61 to 6.42) in the JOA score.Moreover, at 6 months, the pooled analysis of VAS neck pain showed a mean reduction in VAS scores of 4.29 (95% CI: 3.67 to 4.92). At 12 months, the mean difference increased to 4.91 points (95% CI: 4.26 to 5.55), demonstrating further improvement in pain relief over time. By 24 months, the mean VAS reduction was 4.29 points (95% CI: 3.71 to 4.87), suggesting that the pain relief achieved at earlier stages was maintained up to two years postoperatively. This long-term consistency underscores the durability of the intervention. Overall, the pooled VAS reduction across all time points was 4.51 points (95% CI: 4.10 to 4.92). Lastly, the forest plot illustrates the last follow-up of changes in intervertebral disc height. Four studies assessed intervertebral height at the final follow-up after surgery using the endoscopic technique. As shown in the plot, the final follow-up results showed that while there was a slight decrease in intervertebral disc height, it was relatively minimal, with a pooled reduction of 0.26 mm (95% CI: 0.06 to 0.46).

Table 1 Summary of the characteristics of the included studies in the comprehensive review

Study ID	Journal	Region	Design	N/ age	R	Diagnosis	Level	Device	Clinical Assessment	Operation Time	FU (months)	LoS (days)	Advert Events	DC
Nakai S 2000 [21]	Journal of Spinal Disorders	Japan	Case series	24/52	1994	HNP osteophytes	C3-C7	Micro	Excellent, Good, Fair Poor	147	41.0	-	residual bony spur	7
Choi G 2007 [28]	European Spine Journal	Korea	Case series	20/49	2004–2005	HNP, stenosis osteophytes	C6-T1	Micro	VAS, NDI, Prolo score RM	-	16.7	-	none	6×7
Shim CS 2008 [29]	Journal of Spinal Disorders & Techniques	Korea	Case report	1/68	-	HNP	C2-C3	Micro	narrative description	-	7.0	7	CSF leak	5
Sakai T 2009 [30]	Journal of Spinal Disorders & Techniques	Japan	Case series	20/49.9	1989–1995	HNP	C4-C7	Micro	VAS, JOA, RM	-	13y	-	none	7
Choi G 2010 [31]	Minimally Invasive Neurosurgery	Korea	Case series	30/52	2004–2006	HNP, stenosis osteophytes	C4-T1	Micro	NDI, RM	93	35.7	4.3	transit tingling and numbness	-
Kim JS 2011 [32]	European Spine Journal	Korea	Case report	8/59	-	HNP	C5-T1	Micro	VAS, NDI	141.3	8.5	4	transient swallowing difficulty (2)	4×5
Takeuchi M 2012 [33]	Acta Neurochirurgica	Japan	Case series	5/52	2007–2010	HNP osteophytes	C7-T1	Micro	VAS, RM	-	20.0	-	none	7×7
Umebayashi D 2013 [34]	European Spine Journal	Japan	Case series	34/-	2004–2009	HNP osteophytes	C4-T1	Micro	RM, FEA	-	30.0	-	ASD (1) stenosis (1)	6–10
Lowry DW 2015 [35]	International Journal of Spine Surgery	United States	Case series	62/51	-	DDD, HNP	-	Micro	VAS, NDI	-	12.0	1	revision (4)	-
Deng ZL 2016 [36]	Spine	China	Case report	1/37	-	HNP	C4-C5	Endo	VAS, JOA	75	3.0	-	none	-
Quillo-Olvera J 2017 [37]	The Journal of Clinical Neuroscience	Korea	Case report	3/65	-	HNP, stenosis osteophytes	C2-C4 C5-C6	Endo	RM	-	4.3	-	none	-
Du Q 2018 [38]	World Neurosurgery	China	Case series	36/-	2015–2016	HNP	C3-C6	Endo	VAS, JOA, RM	74.7	12	1.6	none	6.5
Chu L 2018 [39]	World Neurosurgery	China	Case series	5/43	2014–2015	HNP	C5-C6	Endo	VAS, JOA	42.8	10.4	-	none	6

Table 1 (continued)

Study ID	Journal	Region	Design	N/ age	R	Diagnosis	Level	Device	Clinical Assessment	Operation Time	FU (months)	LoS (days)	Advert Events	DC
Yu KX 2019 [40]	World Neurosurgery	China	Case series	35/50	2013–2015	HNP	C3-C7	Endo	SF-36, RM	87.5	29.0	5.4	mediastinal effusion endplate collapse	6
Du Q 2019 [41]	BMC Musculoskeletal Disorders	China	Case report	4/44	2016–2016	HNP	C4-C6	Endo	VAS, JOA, MNC	83.8	23.3	1	none	8
Qiao Y 2019 [42]	World Neurosurgery	China	Case report	1/42	-	HNP	C3-C4	Endo	VAS	70	24.0	-	none	7
Kong W 2019 [43]	Journal of Orthopaedic Surgery	China	Case series	32/59	2015–2017	HNP osteophytes	C3-C7	Endo	VAS, JOA, MNC. RM	103.3	24.0	2.7	transient laryngeal spasms	-
Liu X 2019 [44]	International Journal of Clinical and Experimental Medicine	China	Case report	1/44	-	HNP	C5-C6	Endo	VAS, JOA, RM	-	Post	-	None	7–8
Ren Y 2020 [18]	BioMed Research International	China	Cohort study	77/50	2010–2015	HNP	C3-C7	Endo	VAS, MNC, RM	87.5	24.0	-	mediastinal effusion (1) endplate collapse (2)	6
Huang Z 2020 [45]	Journal of International Medical Research	China	Case report	1/44	-	HNP	C5-C6	Endo	VAS, JOA	-	12.0	6	Endplate nonunion	8.18
Yang J 2020 [46]	Journal of Reparative Reconstructive Surgery	China	Case series	21/48	2014–2016	HNP	C3-C7	Endo	VAS, JOA, RM	96.5	85–135	-	none	6
Chen X 2021 [47]	Pain Physician	China	Case series	26/49	2015–2016	HNP	C3-C6	Endo	VAS, JOA, MNC, RM	91.5	19.6	4.1	none	7.5
Kotheeranurak V 2021 [48]	North American Spine Society Journal	Thailand	Case report	1/33	-	Epidural abscess	C2-T1	Endo	narrative description	-	post	-	none	-
Rahman M 2021 [49]	Neurochirurgie	Bangladesh	Case series	40/52.5	2016–2019	HNP	C4-C7	Micro	VAS	-	24	2–3	ASD (3)	5–6
Du Q 2021 [50]	World Neurosurgery	China	Case report	1/44	-	HNP	C4-C5	Endo	VAS, JOA	70	24.0	-	none	-

Table 1 (continued)

Study ID	Journal	Region	Design	N/ age	R	Diagnosis	Level	Device	Clinical Assessment	Operation Time	FU (months)	LoS (days)	Advert Events	DC
Jitpakdee K 2022 [51]	Operative Neurosurgery	Korea	Case report	1/52	-	Metastatic melanoma	C7	Micro	AIS, RM	-	8y	2	CSF leak	6
Ma Y 2022 [19]	BMC Musculoskeletal Disorders	China	Case series	28/59.3	2017–2019	Disc-osteophyte complex	C3-C7	Endo	VAS, JOA, Cobb score	118.4	13.9	3.5	none	6.9
He W 2023 [60]	BMC Musculoskeletal Disorders	China	Case series	12/48.6	2021–2022	Disc-osteophyte complex	C3-C7	Endo	VAS, JOA, Macnab	204.8	18.4	3–4	none	-
Ye S 2023 [20]	World Neurosurgery	China	Case series	24/54.7	2019–2020	HNP	C3-C6	Endo	NDI, VAS, JOA, RM	86.4	24.0	1.4	none	-

Abbreviations: N Number of cases, *R* Recruitment time, *DC* Restriction diameter of drilling channel (mm), *VAS* Visual analog scale, *NDI* Neck disability index, *JOA* Japanese Orthopaedic Association score, *SF-36* 36-Item Short Form Survey Instrument, *MNC* Macnab criteria, *RM* Radiographic measurements, *OPLL* Ossification of the posterior longitudinal ligament, *DDD* Degenerative disc disease, *HNP* Herniated nucleus pulposus, *AIS* Asia impairment scale, *CSF* Cerebrospinal fluid, *FEA* Finite element analysis, *ASD* Adjacent segment disease, *HOS* Hospital of stay (day)

Table 2 Assessment of bias risk in review and analytical studies using the JBI Critical Appraisal Checklist

Cohort Studies	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**%YES/risk**
Ren Y, 2020 [18]	✓	?	?	✗	✗	?	✓	✓	✓	✗	✓	45.5% (High)
Case Series	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	-	-
Nakai S, 2000 [21]	✗	✓	?	✗	✗	✓*	✓*	✓	✗	✗	-	30.0% (High)
Choi G, 2007 [28]	✓	✓	✗	✓	✗	✓*	✓*	✓	✗	✓	-	60.0% (Moderate)
Sakai T, 2009 [30]	✗	✓	✗	✓	✗	✓*	×	✓	✗	✗	-	35.0% (High)
Choi G, 2010 [31]	✓	✓	✓	✓	✓	✓*	✓*	✓	✗	✓	-	80.0% (Low)
Takeuchi M, 2012 [33]	✗	✓	✗	✓	✗	✓*	✓*	✓	✗	✗	-	40.0% (High)
Umebayashi D, 2013 [34]	✓	✓	✓	✓	✗	✓*	✓*	✓	✗	?	-	60.0% (Moderate)
Lowry D, 2015 [35]	✗	✗	✗	✗	?	✓	✗	✓	✗	✓	-	30.0% (High)
Du Q, 2018 [38]	✓	✓	✗	✓	✓	✓*	✓*	✓	✗	✓	-	70.0% (Low)
Chu L, 2018 [39]	✓	✓	✗	✓	✓	✓*	✓*	✓	✗	✗	-	60.0% (Moderate)
Yu KX, 2019 [40]	✓	✓	✓	✓	✗	✓*	✓*	✓	✗	✓	-	70.0% (Low)
Du Q, 2019 [41]	✓	✓	✗	✓	✓	✓*	✗	✓	✗	✗	-	55.0% (Moderate)
Kong W, 2019 [43]	✗	✓	✗	✓	✓	✓*	✓*	✓	✗	✓	-	60.0% (Moderate)
Yang J, 2020 [46]	✓	✓	✗	✓	✓	✓*	×	✓	✗	✓	-	65.0% (Moderate)
Chen X, 2021 [47]	✓	✓	✗	✓	✓	✓*	✓*	✓	✗	✓	-	70.0% (Low)
Rahman M, 2021 [49]	✗	✓	✗	✓	✓	×	✓*	✓	✗	✗	-	45.0% (High)
Ma Y, 2022 [19]	✓	✓	✓	✓	✓	✓	✓*	✓	✗	✓	-	85.0% (Low)
He W, 2023 [60]	✓	✓	✗	✓	✓	✓*	✗	✓	✗	✓	-	65.0% (Moderate)
Ye S, 2023 [20]	✓	✓	✓	✓	✓	✓*	✓	✓	✗	✓		85.0% (Low)
Case Report	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	-	-	-	-
Shim CS, 2008 [29]	✓*	✗	✓	✓	✓	✓	✗	✓	-	-	-	68.8% (Moderate)
Kim JS, 2011 [32]	✓*	✗	✓	✓	✓	✓	✗	✓	-	-	-	68.8% (Moderate)
Deng ZL, 2016 [36]	✓*	✗	✓	✓	✓	✓	✗	✓	-	-	-	68.8% (Moderate)
Quillo-Olvera J, 2017 [37]	✓*	✓	✓	✓	✓	✓	✗	✓	-	-	-	81.3% (Low)
Qiao Y, 2019 [42]	✓*	✓	✓	✓	✓	✓	✗	✓	-	-	-	81.3% (Low)
Liu X, 2019 [44]	✓*	✓	✓	✓	✓	✓	✗	✓	-	-	-	81.3% (Low)
Huang Z, 2020 [45]	✓*	✓	✓	✓	✓	✓	✓	✓	-	-	-	93.8% (Low)
Kotheeranurak V, 2021 [48]	✓*	✓	✓	✓	✓	✓	✗	✓	-	-	-	81.3% (Low)
Du Q, 2021 [50]	✓*	✓	✓	✓	✓	✓	✗	✓	-	-	-	81.3% (Low)
Jitpakdee K, 2022 [51]	✓*	✓	✓	✓	✓	✓	✗	✓	-	-	-	81.3% (Low)

In the Joanna Briggs Institute's risk assessment, detailed in the appendix and based on questions Q1 to Q11, the risk of bias in studies is categorized into three levels: high risk for studies with up to 49% "yes" responses, moderate risk for those scoring 50% to 69% "yes," and low risk for studies exceeding 70% "yes" scores. Symbols used in the assessment include '✓' for yes, '✓*' for yes, '✗' for no, and '?' for unclear responses

This suggests that the endoscopic approach may have a limited impact on disc height maintenance.

Evolution of the anterior transcorporeal (ATc) approach

At the start of the 1950s, pioneers had searched for optimized anterior spinal surgical approaches to expose the cervical spine. The pre-sternocleidomastoid approach was earlier reported by Henry via the retropharyngeal and retro-carotid route to access the cervical vertebral artery [22]. Smith-Robinson's approach via the retropharyngeal and pre-carotid was then described for use in central or paramedian soft disc protrusion cases. However, in some instances, they also report the subsequent pathologic changes of disc degeneration, such as disc height change or spinal instability [7, 23]. Moreover, scholars have been concerned about whether spinal surgery accelerates adjacent segment degeneration (ASD) at the operation level, which is still under debate [24].

Nevertheless, after Cloward described his specific manual drill used for the ATd approach to access the spinal canal and remove the disc fragment [8], the idea of eliminating disease generators through a customized surgical procedure started to sprout and evolved in the last several decades. Jho et al. [25, 26] first described the microsurgical transuncal foraminotomy, which decreased the violation of the internal structure of the intervertebral space to perform what he called "functional spine surgery." However, the surgical trajectory and retractor

placement with muscle dissection increased the risk of injury to the vertebral artery and sympathetic chain that lies in the ventral and lateral border of the longus colli muscles [27]. Nakai et al. [21] published a case series of 24 patients diagnosed with disc herniation. They are all treated by using the technique of herniotomy via the AMTc approach. They reported the achievement of good results. However, they mentioned that such good results might not be achieved every time, especially in patients with large osteophytes that are difficult to resect satisfactorily.

Drilling tunnel sizes and safety concerns of the biomechanics

Both the diameter and volume of bone violation during the process of drilling tunnels are essential. The suggested restriction of diameter restriction in microscopic or full-endoscopic procedures ranges from around 4×5 to 8×8 mm from our included studies [18, 21, 28–51]. Other studies concerning the degree of volume violations on the vertebral body and its impact on spinal stability have been reported. Umebayashi et al. [34] initially performed a finite element analysis based on the volume of bone removal in their midterm case series report. They concluded that in the drilled vertebral body group, the strength to tolerate before the fracture happened was lower than in the intact vertebral body group. However, there were no clinical differences between them, and the strength of the drilled vertebral body group was still stronger than that of the drilled pedicle group. Wu et al. [52] reported another biomechanical analysis. They found that the endplate excision exceeds 8 mm, or the diameter of the drill tunnel that is over 10 mm is not recommended. Furthermore, the stress on the lateral wall of the drilling tunnel was positively correlated with tunnel diameter. When the upper endplate damage is combined with the excessive cross-sectional diameter of the drilling tunnel, endplate fracture risk increases. These results were also proven by Huang et al. [45] in another study.

Regarding the biomechanical comparison between the ATc and the ATd model, a recently published study optimized the finite model and reconstructed the uncovertebral joints in their analysis and found that the uncovertebral joints play a significant role in sharing the vertebral column's load. The posterior part of these joints supports more to maintain segmental stability than the anterior part. Nevertheless, removing these joints would eventually transfer a more compressive load to the adjacent disc and may further accelerate the disc degeneration process [53]. These biomechanical results concluded that the vertebral body strength in the ATc model was preserved and might be the closest model to the physiological spine compared to the ATd model, which usually violates the intervertebral disc space and the nearby uncovertebral joints. Until now, the finite element analysis has still not been enough to mimic the spine's complex structure compared to the in vivo physiological state because of the lack of specific material properties and accurate condition values from organisms to use in the experiment.

Clinical outcomes and complications of the anterior transcorporeal (ATc) approach

Various research has been published to support the evidence of the ATc approach. Sakai et al. [54] reported microscopic-based surgical results with more than ten years of follow-up time. Although the mobility of the spine at the operated level decreased, there was no clear evidence of the occurrence of ASD, and all follow-up patients yielded promising clinical results. They also speculated that the process of spontaneous bony fusion they found was initiated with some endplate destruction during their procedure. The mesenchymal stem cells, which are located in the vertebral bone marrow carrying the BMP-2 gene, have been released. Therefore, this will induce intradiscal bone formation. Another study also speculated these findings in their study, as an endoscopic-based retrospective cohort study by Ren et al. [18] indicated that all of the drilling tunnels were spontaneously closed by the bone healing process in their series. Regarding their clinical outcomes, no difference in the VAS of the arm and neck pain between the AETc and the AETd approach was found in their cohorts. Nevertheless, the mean operative time of the AETc was longer. It also had a significant height change in the intervertebral space and vertebral body with a total of 5.7% endplate collapse but without the report of any radiographic instability. They concluded that maintaining this structural integrity depends on how much the ligament complex and the vertebral body have been preserved and recommended restricting the diameter of the drill tunnel to a maximum of 6 mm to avoid an endplate collapse.

Not limited to cervical disc pathology, recently, Kotheeranurak et al. [48] successfully performed surgical drainage of the long-span retropharyngeal and epidural abscess by combining the use of the endoscopy and the nasogastric tube via AETc. Because the transcorporeal drilling tunnel is very small and does not violate the mechanical integrity of the vertebral body much, this novel technique avoids additional instrumentation or fusion procedures, which are usually mandatory following conventional techniques, such as anterior corpectomy or discectomy. They recommended promoting the use of these techniques, especially in those with multiple comorbidities or immunocompromised patients. Their team also expanded its use in neoplastic disease,

as reported in another long-term follow-up case report resectioning the C7 intradural extramedullary metastatic melanoma using the AMTc technique [51]. The result is also optimal, as the patient's myelopathic symptoms improved significantly, and no local recurrence had been reported. (Figs. 3, 4).

Regarding the complication rates, as the ATc approach has its specific surgical approach, the approach-related complications, such as dysphagia or esophageal perforation, are theoretically less than other cervical spine procedures [55–60]. Only one patient reported experiencing transient laryngeal spasms and upper airway obstruction,

Fig. 3 A 75-year-old male with a history of progressive quadriparesis (grade II) following anterior cervical discectomy and fusion at levels C4-C5 and C6-C7 for cervical spinal stenosis. Since November 2013, he has experienced worsening gait disturbances, upper and lower extremity motor weakness, sensory deficits including paresthesia and hypesthesia below the C5 dermatome, and partial impairment of anal tone, causing difficulties with voiding and defecation

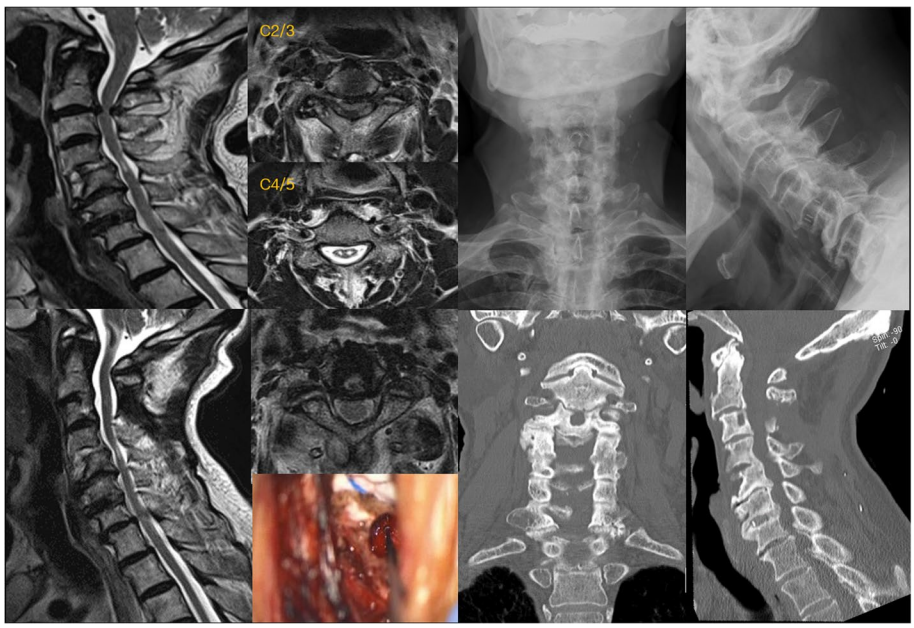

Fig. 4 A 52-year-old female with a history of brain melanoma, previously suspected of cerebrospinal fluid seeding. She has shown no evidence of tumor recurrence or instability during a 72-month follow-up period after undergoing a transcorporeal approach for spinal decompression

which were successfully resolved after administering the pressurized oxygen [43]. One single-arm meta-analysis study also reported interesting findings [61]. Although they seem to have a high heterogeneity among the included studies, they found that the ATc approach reported acceptable clinical outcomes with only a 3% incidence of adverse events, including cerebrospinal fluid leakage, swallowing difficulty, adjacent segment disease instability, the collapse of the adjacent endplates, and mediastinal effusion. Nevertheless, these reports were all published by experienced endoscopic spine surgeons who were pioneers in these techniques and already proficient in MISS. Therefore, difficulty in the learning curve process is expected. Moreover, the relatively longer operative time in inexperienced surgeons may increase intraoperative complication risk during their initial learning phase. Strict adherence to indications for patient selection is important and might be crucial to obtaining satisfactory clinical outcomes.

Discussion

The ATc approach represents a pivotal element in the armamentarium of spine surgeons, particularly in certain cervical spine surgeries. This technique is exceptionally beneficial when addressing pathologies located anteriorly in the spinal canal. Its primary advantage lies in facilitating access without necessitating extensive destruction of bone or surrounding soft tissues, thereby preserving spinal stability. This approach is particularly advantageous in complex scenarios, such as when accessing anterior pathologies at the extreme upper or lower cervical levels. These regions are often obstructed by the patient's anatomical structures. By initiating from the more accessible middle cervical level, strategic planning of the ATc trajectory can significantly reduce morbidity compared to traditional approaches. Such traditional methods may involve complications like dysphagia or hoarseness due to excessive traction of surrounding soft tissues, the necessity of additional procedures like manubrectomy or mandibulectomy, or resorting to transoral or transthoracic approaches [62, 63]. Shim et al. has exemplified the effectiveness of this technique, reporting the successful treatment of a patient with C2-3 calcified disc herniation using an ATc approach [29]. Despite an incidental durotomy during surgery, the dural sac was effectively sealed with fibrin glue, leading to the patient's full recovery within a seven-month follow-up period. Similarly, another study demonstrated the use of the ATc approach for decompressing the C7-T1 level. The unique anatomical tilt of the cervicothoracic vertebrae in this method allows the surgical trajectory to circumvent the clavicle bone or manubrium. This reduces the amount of disc material that needs to be resected and potentially eliminates the necessity for a fusion procedure in the cervicothoracic junctional segment [64].

The rapid adoption of full-endoscopic spine surgery over the past decade is a testament to its advancements and the consistently positive clinical outcomes it has demonstrated in comparison to conventional spinal procedures [65–67]. Its applicability has expanded from the lumbar region to encompass the thoracic and cervical spine, showcasing its versatility [68]. Some pioneering surgeons are now exploring the potential of anterior full-endoscopic transcorporeal technique (AETc). This method is particularly promising due to its ultra-minimally invasive nature, which could potentially result in even less soft tissue injury than the traditional anterior microscopic transcorporeal approach (AMTc). While the choice between AETc and AMTc techniques remains a subject of ongoing debate, there is yet to be conclusive evidence favoring one over the other. Financial considerations also play a role in this debate; the cost of full-endoscopic equipment may be higher compared to microscopic techniques, impacting its adoption and widespread use. Comparative studies have found that both microscopic and endoscopic procedures offer superior outcomes compared to conservative or traditional surgical treatments. However, challenges remain, such as dealing with severe ossification of the posterior longitudinal ligament or ensuring complete lesion removal in cases of adhesion [69–71]. In our assessment, the AMTc may offer a slight edge over AETc methods for anterior transcorporeal applications. This advantage stems from the flexibility of microscopic instruments, which are not confined to a working channel as endoscopic tools are. Consequently, the diameter of the transcorporeal tunnel, determined by the drilling size, can accommodate a broader range of instrument sizes with the microscopic approach. This flexibility results in comparatively less damage to the anterior portion of the vertebral body. Additionally, the working angle of the distal end of instruments in AMTc is typically larger, which can be advantageous. Therefore, the application of AETc might present more challenges, especially when accessing peripheral areas.

The ATd approach represents an alternative method in anterior endoscopic cervical surgery. Characterized by its pathway through the intervertebral disc space to access the pathology, this approach offers several benefits. Primarily, it negates the need to drill through bone, simplifying the procedure and reducing overall operative time. Nonetheless, when compared to the ATc approach, the ATd method has its limitations. The act of invading the intervertebral disc space may accelerate its degeneration process. Furthermore, in instances where the disc space is already severely narrowed, the maneuverability of the

endoscope might be significantly restricted, or it might not be possible to pass it without damaging the vertebral endplates. On the other hand, the ATc approach offers distinct advantages in terms of the healing process. The bony healing associated with this method is theoretically capable of occurring without substantial loss of mechanical strength. In contrast, the healing process in the ATd approach, involving the intervertebral disc space composed of collagen and cartilaginous tissue, results in a fibrous scar. This scarring could potentially compromise the overall integrity of the cervical spine joint complex. A comprehensive comparison of the advantages and disadvantages of these two techniques is detailed in Table 3. To facilitate the ATc bony healing process, Du et al. employed autogenous bone grafts harvested during the tunneling process with trephines and high-speed burrs. This approach not only controls the orientation of the endoscopic channel but also reduces the risk of implant migration, as demonstrated in their treatment of a patient with symptomatic adjacent segment disease (ASD) following anterior cervical discectomy and fusion (ACDF) surgery, yielding positive results [41]. Similarly, Lowry et al. reported successful outcomes using a combination of beta-tricalcium phosphate implant and harvested autogenous bone graft, showcasing its potential for effective bony tunnel repair [35].

In practing the AMTc and AETc, notable differences in technique may impact the surgical experience. Regarding instrument flexibility, the AMTc accommodates a wide range of conventional instrument. In contrast, the AETc is constrained by the narrow working channel of the endoscope, which might limit instrument options; however, the AETc employ continuous saline irrigation, which helps maintain a clear operative field and facilitates more meticulous floating manipulation of the dural sac (Table 4). For beginners embarking on AETc procedures, Deng et al. offer crucial advice to enhance safety and efficacy. They recommend less experienced surgeons undertake more extensive stripping of the prevertebral soft tissue and adjacent vascular structures, as opposed to relying solely on blunt finger techniques. This meticulous preparation, coupled with the use of a blunted puncture needle and a non-beveled sheath, significantly enhances the safety of trocar placement [36]. Additionally, the utilization of surgical navigation systems and high-resolution imaging is invaluable in ensuring the safe insertion of the endoscopic working channel. Preoperative planning, including the customization of the surgical trajectory, is imperative to navigate the intricate anatomy of the cervical spine effectively [18, 29, 46, 49, 72]. Our experience, as aligned with previous studies, suggests that the success of AETc is contingent not only on the surgeon's skill but also critically on the location of the pathology [32, 37]. For example, in cases where the pathology is located in the central or paracentral region above the C5 level, such as at C2-3 or C3-4, the initial drilling should start from the caudal side of the vertebral body, following a caudocephalic trajectory. In contrast, for pathologies below C5, the starting point and trajectory should be reversed. Furthermore, for more complex pathologies like spinal stenosis or neoplastic diseases, larger drill diameters may be employed without compromising physiological load-bearing capacities, as evidenced by biomechanical studies [45, 52, 53]. In such scenarios, the initial drilling might commence at the vertebral center, gradually expanding in a funnel-like manner. This technique increases the working channel's cross-sectional area within the bone, thereby facilitating instrument manipulation and targeting the pathology more precisely.

The ATc approach, like other advanced spine surgery techniques, faces challenges in terms of training and adoption. The ATc approach also presents risks and limitations that need to be carefully considered. One of the primary risks associated with the ATc approach is the potential compromise of vertebral integrity due to drilling larger tunnels or removing excessive bone during the procedure, which can weaken the vertebral body, especially for the patient who has osteoporosis. While less invasive than traditional methods, the ATc approach still carries the risk of complications such as dysphagia,

Table 3 Comparisons between the anterior cervical transcorporeal and the transdiscal approach

Parameters/Issues	Transcorporeal Approach	Transdiscal Approach
Access Route	Via vertebral body bone	Via intervertebral disc material
Disc Dissection	Minimal; avoids disc damage	Extensive; affects residual disc
Mechanical Integrity	Maintained; if the drilling pathway is confined	Compromised; increased adjacent segment load transfer
Bone Drilling	Necessary; longer operative time potential	Unnecessary; shorter operative time potential
Healing Process	Bony union; mechanical strength retained	Fibrous scar formation; spinal integrity compromised
Disc Degeneration	Disc degeneration risk mitigated; no degeneration acceleration	Potential acceleration of disc degeneration
Narrow Disc Spaces	Feasible in narrowed disc spaces	Challenging or infeasible in severely narrowed disc spaces

Table 4 Comparisons between the anterior cervical microscopic and the full-endoscopic transcorporeal approach

Feature	Anterior Microscopic Transcorporeal Approach (AMTc)	Anterior Full-Endoscopic Transcorporeal Approach (AETc)
Visualization Method	Uses a surgical microscope for enhanced visualization	Utilizes a full-endoscope for minimally invasive visualization
Instrument Flexibility	Flexible for the use of various instrument	Limited by the narrow working channel
Tunnel Diameter	allows a larger tunnel size, providing better access to different areas of the vertebral body	Requires a smaller tunnel, restricting some surgical maneuvers
Tissue Preservation	Causes more tissue disruption	Minimal tissue disruption, preserving soft tissue better
Disc Degeneration Risk	Potential for accelerated disc degeneration	Disc degeneration risk mitigated
Saline Irrigation and its Related Complication	No	Yes
Applications	More versatile in treating a wider range of pathologies	Best suited for cases requiring minimal invasion and precision in localized areas

laryngeal spasms, and CSF leaks. Moreover, Surgeons less familiar with the ATc approach may experience longer operative times, particularly during their initial learning phase. This increases the risk of intraoperative complications, especially in complex cases involving large osteophytes or ossifications of the posterior vertebral area.

To solve this issue, surgeons must develop highly specialized skills in microscopic or endoscopic navigation and instrument manipulation through small anatomical corridors. This requires mastering new hand–eye coordination techniques distinct from traditional open surgeries, which can be difficult for experienced surgeons accustomed to conventional approaches. Moreover, the adoption of this technique is further complicated by the lack of standardized training protocols. Currently, many surgeons rely on industry-sponsored cadaver workshops, which may not provide the extensive hands-on experience needed to achieve proficiency. This creates inconsistencies in skill levels among practitioners, potentially leading to variable clinical outcomes. To address these issues, hospitals and surgical societies must implement formalized, simulation-based training and mentorship programs to ensure surgeons receive the necessary practice and guidance. Another hurdle is the cost and availability of the specialized equipment required for ATc cervical surgery. Nevertheless, it is still a fact that not all healthcare institutions can afford all the tools, such as microscopic, endoscopic, or even intraoperative navigation systems, to be used and applied in their practices.

Our study, structured as a comprehensive review, endeavors to integrate methodologies typically reserved for reviews and meta-analyses to enhance the validity and reliability of our findings. The transcorporeal approach is a relatively new technique, and the available clinical evidence, while promising, is limited in terms of large-scale studies and long-term follow-up data. Meanwhile, there is an absence of dedicated studies assessing its cost-effectiveness. We observed a pronounced emphasis on ATc studies within East Asian regions, with a significant proportion of research emanating from identical groups of investigators. This concentration, both geographically and among specific research teams, has introduced a degree of heterogeneity into the results, potentially affecting the generalizability of our conclusions. Moreover, our research compilation reveals a conspicuous absence of prospective randomized controlled trials and studies with extended follow-up periods. Given these considerations, it is evident that an imperative need exists for more diversified and comprehensive research endeavors. Such efforts would enable a more robust and nuanced assessment of the efficacy and applicability of ATc techniques across various clinical settings and populations.

Conclusion

This comprehensive review highlights the advancements and growing evidence of the ATc approach. Our findings underline the core benefits of the ATc technique, including its ability to provide effective decompression while minimizing damage to intervertebral discs and preserving the biomechanical integrity of the vertebral body.

Currently, the biomechanical analyses using finite element models further support the safety and efficacy of the ATc approach, enhancing confidence in its clinical application. Despite some minor complications, such as transient dysphagia and occasional laryngeal spasms, the overall complication rate remains low, especially when performed by experienced surgeons. The integration of contemporary navigation, imaging-assisted technology, and improved surgical instruments has significantly shortened the learning curve for surgeons adopting this method, further enhancing its safety and effectiveness. As we continue to refine the ATc technique and explore its applications in more complex cases, it becomes evident that this approach has potential become a alternative approach for anterior cervical spine pathologies.

Abbreviations

MIS	Minimally invasive surgery
ASD	Adjacent spine degeneration
ATd	Anterior transdiscal approach
ATc	Anterior transcorporeal approach
ACDF	Anterior cervical discectomy and fusion
AMTc	Anterior microscopic transcorporeal approach
AETc	Anterior full-endoscopic transcorporeal approach

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12893-024-02611-z.

Supplementary Material 1.

Acknowledgements
We would like to express our sincere gratitude and respect to all the pioneers whose groundbreaking work has paved the way for the development of the transcorporeal approach in managing cervical spine disorders. Additionally, we extend our heartfelt thanks to Mr. Hong Jiang from the Art College of Jilin University, Changchun, China, for his valuable contribution to the illustrations in this research.

Authors' contributions
Yanting Liu and Siravich Suvithayasiri are designated as co-first authors and have contributed equally to this work. Y.L. and S.S. designed the study, conducted the analysis, collaborated on the clinical data collection, interpretation and drafted the manuscript. V.K., F.V.I., K.J., J.B., K-C.C. and G.C. contributed to revised the manuscript for important intellectual content. J-S.K. supervised the entire project, secured funding, and reviewed the final manuscript.
Y.L. and S.S. designed the study, conducted the analysis, collaborated on the clinical data collection, interpreted, and drafted the manuscript. V.K., F.V.I., K.J., J.B., K-C.C., and G.C. contributed to revising the manuscript for important intellectual content. J-S.K. supervised the entire project, secured funding, and reviewed the final manuscript.

Funding
This research was supported by a grant of Patient-Centered Clinical Research Coordinating Center (PACEN) funded by the Ministry of Health & Welfare, Republic of Korea (grant number: RS-2020-KH096076).

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was approved by the ethics committee of The Catholic University of Korea Seoul St. Mary's Hospital, and it has followed the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
Jin-Sung Kim is a consultant for RIWOSpine, GmbH, Germany, Stöckli Medical AG, Switzerland and Elliquence, LLC, USA.

Author details
[1]Department of Neurosurgery, College of Medicine, Seoul St. Mary's Hospital, The Catholic University of Korea, 222 Banpo-daero, Seocho-gu, Seoul 06591, Republic of Korea. [2]Department of Orthopedics, Chulabhorn Hospital, Chulabhorn Royal Academy, Bangkok, Thailand. [3]Bone and Joint Excellence Center, Thonburi Hospital, Bangkok, Thailand. [4]Latinamerican Endoscopic Spine Surgery Society, Hospital Privado de Rosario, Argentina, Rosario. [5]Department of Orthopaedics, Faculty of Medicine, Chulalongkorn University, Bangkok, Thailand. [6]Department of Orthopedics, Thai Red Cross Society, Queen Savang Vadhana Memorial Hospital, Bangkok, Thailand. [7]Department of Neurosurgery, Seoul Top Spine Hospital, Goyangsi, South Korea. [8]Neurosurgeon/Spine Surgeon and Medical Director, Pohang Woori Hospital, Pohang, South Korea. [9]Department of Neurosurgery, Wooridul Spine Hospital, Seoul, South Korea.

Received: 26 July 2024 Accepted: 3 October 2024
Published online: 16 October 2024

References

1. Parker SL, Godil SS, Cheng JS, Devin CJ, McGirt MJ. Anterior Approach for Cervical Surgery is Associated with Decreased Surgical Morbidity Compared to Posterior Approach: Analysis of 9,698 patients from NSQIP Database. The Spine Journal. 2014;14(11, Supplement):S45.
2. Fehlings MG, Barry S, Kopjar B, et al. Anterior versus posterior surgical approaches to treat cervical spondylotic myelopathy: outcomes of the prospective multicenter AOSpine North America CSM study in 264 patients. Spine (Phila Pa 1976). 2013;38(26):2247–52.
3. Maiman DJ, Kumaresan S, Yoganandan N, Pintar FA. Biomechanical effect of anterior cervical spine fusion on adjacent segments. Biomed Mater Eng. 1999;9(1):27–38.
4. Barbagallo GM, Corbino LA, Olindo G, Albanese V. Heterotopic ossification in cervical disc arthroplasty: Is it clinically relevant? Evid Based Spine Care J. 2010;1(1):15–20.
5. Kong L, Ma Q, Meng F, Cao J, Yu K, Shen Y. The prevalence of heterotopic ossification among patients after cervical artificial disc replacement: a systematic review and meta-analysis. Medicine (Baltimore). 2017;96(24):e7163.
6. Arts MP. Commentary: inimally invasive spine surgery: new standard or transient fashion? Spine J. 2013;13(5):498–500.
7. Smith GW, Robinson RA. The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion. J Bone Joint Surg Am. 1958;40-a(3):607–24.
8. Cloward RB. The anterior approach for removal of ruptured cervical disks. J Neurosurg. 1958;15(6):602–17.
9. Yang JS, Chu L, Chen L, Chen F, Ke ZY, Deng ZL. Anterior or posterior approach of full-endoscopic cervical discectomy for cervical intervertebral disc herniation? A comparative cohort study. Spine (Phila Pa 1976). 2014;39(21):1743–50.
10. Ruetten S, Komp M, Merk H, Godolias G. Full-endoscopic anterior decompression versus conventional anterior decompression and fusion in cervical disc herniations. Int Orthop. 2009;33(6):1677–82.
11. Hilibrand AS, Robbins M. Adjacent segment degeneration and adjacent segment disease: the consequences of spinal fusion? Spine J. 2004;4(6 Suppl):190s-s194.
12. Sun MS, Yuchi CX, Cai XY, Du CF, Mo ZJ. Parametric study of anterior percutaneous endoscopic cervical discectomy (APECD). Comput Methods Biomech Biomed Engin. 2021;24(6):687–99.
13. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. BMJ. 2009;339:b2535.
14. Kim K, Isu T, Sugawara A, Matsumoto R, Isobe M. Anterior decompression via a wide transvertebral approach and a ceramic insert in a patient with cervical degenerative disease. Surg Neurol. 2007;67(2):127–33 discussion 33–4.
15. Hong WJ, Kim WK, Park CW, et al. Comparison between transuncal approach and upper vertebral transcorporeal approach for unilateral cervical radiculopathy - a preliminary report. Minim Invasive Neurosurg. 2006;49(5):296–301.
16. George B, Zerah M, Lot G, Hurth M. Oblique transcorporeal approach to anteriorly located lesions in the cervical spinal canal. Acta Neurochir (Wien). 1993;121(3–4):187–90.
17. Zhang D, Fan T, Fan W, Zhao X. Anterior cervical transvertebral approach for resection of an intraspinal ventral lesion: illustrative case. J Neurosurg: Case Lessons JNSCL. 2021;1(17):CASE2190.
18. Ren Y, Yang J, Chen CM, et al. Outcomes of discectomy by using full-endoscopic visualization technique via the transcorporeal and transdiscal approaches in the treatment of cervical intervertebral disc herniation: a comparative study. Biomed Res Int. 2020;2020:5613459.
19. Ma Y, Xin Z, Kong W, Zhang L, Du Q, Liao W. Transcorporeal decompression using a fully-endoscopic anterior cervical approach to treat cervical

spondylotic myelopathy: surgical design and clinical application. BMC Musculoskelet Disord. 2022;23(1):1031.
20. Ye S, Li DL, Kong WJ, et al. Surgical essentials and 2-year follow-up results of channel repair in endoscopic transcorporeal discectomy for cervical disc herniation. World Neurosurg. 2023;182:e755–63.
21. Nakai S, Yoshizawa H, Kobayashi S, Hayakawa K. Anterior transvertebral herniotomy for cervical disk herniation. J Spinal Disord. 2000;13(1):16–21.
22. Arnold KH. Extensile exposure. BJS (Br J Surg). 1957;45(189):111.
23. Robinson R. Anterolateral disc removal and interbody fusion for cervical disc syndrome. Bull Johns Hopkins Hosp. 1955;96:223–4.
24. Denaro V, Di Martino A. Cervical spine surgery: an historical perspective. Clin Orthop Relat Res. 2011;469(3):639–48.
25. Jho HD. Microsurgical anterior cervical foraminotomy for radiculopathy: a new approach to cervical disc herniation. J Neurosurg. 1996;84(2):155–60.
26. Jho HD, Kim WK, Kim MH. Anterior microforaminotomy for treatment of cervical radiculopathy: part 1–disc-preserving "functional cervical disc surgery." Neurosurgery. 2002;51(5 Suppl):S46-53.
27. Yin Z, Yin J, Cai J, Sui T, Cao X. Neuroanatomy and clinical analysis of the cervical sympathetic trunk and longus colli. J Biomed Res. 2015;29(6):501–7.
28. Choi G, Lee SH, Bhanot A, Chae YS, Jung B, Lee S. Modified transcorporeal anterior cervical microforaminotomy for cervical radiculopathy: a technical note and early results. Eur Spine J. 2007;16(9):1387–93.
29. Shim CS, Jung TG, Lee SH. Transcorporeal approach for disc herniation at the C2–C3 level: a technical case report. J Spinal Disord Tech. 2009;22(6):459–62.
30. Sakai T, Katoh S, Sairyo K, et al. Anterior transvertebral herniotomy for cervical disc herniation: a long-term follow-up study. J Spinal Disord Tech. 2009;22(6):408–12.
31. Choi G, Arbatti NJ, Modi HN, et al. Transcorporeal tunnel approach for unilateral cervical radiculopathy: A 2-Year Follow-Up Review and Results. Minim Invasive Neurosurg. 2010;53(3):127–31.
32. Kim JS, Eun SS, Prada N, Choi G, Lee SH. Modified transcorporeal anterior cervical microforaminotomy assisted by O-arm-based navigation: a technical case report. Eur Spine J. 2011;20 Suppl 2(Suppl 2):S147-52.
33. Takeuchi M, Takayasu M, Yasuda M, et al. Transvertebral anterior key hole foraminotomy without fusion for the cervicothoracic junction. Acta Neurochir (Wien). 2012;154(10):1797–802.
34. Umebayashi D, Hara M, Nakajima Y, Nishimura Y, Wakabayashi T. Transvertebral anterior cervical foraminotomy: midterm outcomes of clinical and radiological assessments including the finite element method. Eur Spine J. 2013;22(12):2884–90.
35. Lowry DW, Tuinstra SM, Liang K, Sclafani JA. Clinical outcomes after cervical transcorporeal microdecompression and vertebral body access channel repair. Int J Spine Surg. 2015;9:10.
36. Deng ZL, Chu L, Chen L, Yang JS. Anterior transcorporeal approach of percutaneous endoscopic cervical discectomy for disc herniation at the C4–C5 levels: a technical note. Spine J. 2016;16(5):659–66.
37. Quillo-Olvera J, Lin GX, Suen TK, Jo HJ, Kim JS. Anterior transcorporeal tunnel approach for cervical myelopathy guided by CT-based intraoperative spinal navigation: echnical note. J Clin Neurosci. 2018;48:218–23.
38. Du Q, Wang X, Qin JP, et al. Percutaneous full-endoscopic anterior transcorporeal procedure for cervical disc herniation: a novel procedure and early follow-up study. World Neurosurg. 2018;112:e23–30.
39. Chu L, Yang JS, Yu KX, Chen CM, Hao DJ, Deng ZL. Usage of bone wax to facilitate percutaneous endoscopic cervical discectomy via anterior transcorporeal approach for cervical intervertebral disc herniation. World Neurosurg. 2018;118:102–8.
40. Yu KX, Chu L, Yang JS, et al. Anterior transcorporeal approach to percutaneous endoscopic cervical diskectomy for single-level cervical intervertebral disk herniation: case series with 2-year follow-up. World Neurosurg. 2019;122:e1345–53.
41. Du Q, Lei LQ, Cao GR, et al. Percutaneous full-endoscopic anterior transcorporeal cervical discectomy and channel repair: a technique note report. BMC Musculoskelet Disord. 2019;20(1):280.
42. Qiao Y, Liao WB, Du Q, et al. Percutaneous full-endoscopic anterior transcorporeal diskectomy for massive migrated cervical disk herniation treatment: case report and review of the literature. World Neurosurg. 2019;132:47–52.
43. Kong W, Xin Z, Du Q, Cao G, Liao W. Anterior percutaneous full-endoscopic transcorporeal decompression of the spinal cord for single-segment cervical spondylotic myelopathy: the technical interpretation and 2 years of clinical follow-up. J Orthop Surg Res. 2019;14(1):461.
44. Liu X, Sun N, Sun ZZ, Fang QM, Huang Z. Effect of transcorporeal percutaneous endoscopic cervical discectomy on vertebral integrity. Int J Clin Exp Med. 2019;12(2):1997–2003.
45. Huang Z, Li Y, Liu H, et al. Upper endplate nonunion after transcorporeal percutaneous endoscopic cervical discectomy: a case report. J Int Med Res. 2020;48(5):300060520922684.
46. Yang J, Chu L, Deng Z, et al. Clinical study of single-level cervical disc herniation treated by full-endoscopic decompression via anterior transcorporeal approach. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi. 2020;34(5):543–9.
47. Chen X, Gao JA, Du Q, Qiao Y, Kong WJ, Liao WB. Percutaneous full-endoscopic anterior transcorporeal cervical discectomy for the treatment of cervical disc herniation: surgical design and results. Pain Physician. 2021;24(6):E811–9.
48. Kotheeranurak V, Jitpakdee K, Singhatanadgige W, Limthongkul W, Yingsakmongkol W, Kim J-S. Anterior transcorporeal full-endoscopic drainage of a long-span ventral cervical epidural abscess: a novel surgical technique. North Am Spine Soc J (NASSJ). 2021;5:100052.
49. Rahman MM, Moscote-Salazar LR, Garcia-Ballestas E. Outcomes and technical issues of transcorporeal anterior cervical microforaminotomy in patients with cervical brachialgia. Neurochirurgie. 2021;67(5):445–9.
50. Du Q, Zhang MB, Kong WJ, et al. A novel technique of endoscopic anterior transcorporeal approach with channel repair for adjacent segment disease after anterior cervical discectomy and fusion. World Neurosurg. 2021;154:109–16.
51. Jitpakdee K, Kotheeranurak V, Lim WJ, Kim JS. Anterior transcorporeal approach for cervical metastatic melanoma resection guided by o-arm-navigated intraoperative computed tomography. Oper Neurosurg (Hagerstown). 2022;22(1):e7–11.
52. Wu WK, Yan ZJ, Zhang TF, et al. Biomechanical influences of transcorporeal tunnels on c4 vertebra under physical compressive load under flexion movement: a finite element analysis. World Neurosurg. 2018;114:e199–208.
53. He T, Zhang J, Yu T, et al. Comparative analysis of the biomechanical characteristics after different minimally invasive surgeries for cervical spondylopathy: a finite element analysis. Front Bioeng Biotechnol. 2021;9:9.
54. Riew KD, Lou J, Wright NM, Cheng SL, Bae KT, Avioli LV. Thoracoscopic intradiscal spine fusion using a minimally invasive gene-therapy technique. J Bone Joint Surg Am. 2003;85(5):866–71.
55. Chang CJ, Liu YF, Hsiao YM, et al. Comparison of anterior cervical discectomy and fusion versus artificial disc replacement for cervical spondylotic myelopathy: a meta-analysis. J Neurosurg Spine. 2022;37(4):569–78.
56. Guo L, Wang J, Zhao Z, et al. Microscopic anterior cervical discectomy and fusion versus posterior percutaneous endoscopic cervical keyhole foraminotomy for single-level unilateral cervical radiculopathy: a systematic review and meta-analysis. Clin Spine Surg. 2022;36(2):59–69.
57. Song J, Yi P, Wang Y, et al. The retropharyngeal steroid use during operation on the fusion rate and dysphagia after ACDF? A systematic review and meta-analysis. Eur Spine J. 2022;31(2):288–300.
58. Fountas KN, Kapsalaki EZ, Nikolakakos LG, et al. Anterior cervical discectomy and fusion associated complications. Spine (Phila Pa 1976). 2007;32(21):2310–7.
59. Yee TJ, Swong K, Park P. Complications of anterior cervical spine surgery: a systematic review of the literature. J Spine Surg. 2020;6(1):302–22.
60. He W, Du Q, Wang ZJ, et al. Anterior percutaneous full-endoscopic transcorporeal decompression of the spinal cord via one vertebra with two bony channels for adjacent two-segment cervical spondylotic myelopathy: a technical note. BMC Musculoskelet Disord. 2023;24(1):844.
61. Apostolakis S. Transcorporeal tunnel approach for cervical radiculopathy and myelopathy: a systematic review and meta-analysis. World Neurosurg. 2020;138:318–27.
62. Russo A, Albanese E, Quiroga M, Ulm AJ. Submandibular approach to the C2–3 disc level: microsurgical anatomy with clinical application. J Neurosurg Spine. 2009;10(4):380–9.
63. Laus M, Pignatti G, Malaguti MC, Alfonso C, Zappoli FA, Giunti A. Anterior extraoral surgery to the upper cervical spine. Spine (Phila Pa 1976). 1996;21(14):1687–93.

64. Yamazaki S, Kokubun S, Ishii Y, Tanaka Y. Courses of cervical disc herniation causing myelopathy or radiculopathy: an analysis based on computed tomographic discograms. Spine (Phila Pa 1976). 2003;28(11):1171–5.
65. Chin BZ, Yong JH, Wang E, et al. Full-endoscopic versus microscopic spinal decompression for lumbar spinal stenosis: a systematic review & meta-analysis. Spine J. 2024;24(6):1022–33.
66. Liu Y, Kim Y, Park CW, Suvithayasiri S, Jitpakdee K, Kim JS. Interlaminar endoscopic lumbar discectomy versus microscopic lumbar discectomy: a preliminary analysis of L5–S1 lumbar disc herniation outcomes in prospective randomized controlled trials. Neurospine. 2023;20(4):1457–68.
67. Beck J, Westin O, Klingenstierna M, Baranto A. Full-endoscopic lumbar discectomy vs standard discectomy: a noninferiority study on clinically relevant changes. Int J Spine Surg. 2023;17(3):364–9.
68. Jitpakdee K, Liu Y, Heo DH, Kotheeranurak V, Suvithayasiri S, Kim JS. Minimally invasive endoscopy in spine surgery: where are we now? Eur Spine J. 2023;32(8):2755–68.
69. Haden N, Latimer M, Seeley HM, Laing RJ. Loss of inter-vertebral disc height after anterior cervical discectomy. Br J Neurosurg. 2005;19(6):469–74.
70. Jin C, Wang Z, Liu P, Liu Y, Wang Z, Xie N. A biomechanical analysis of anterior cervical discectomy and fusion alone or combined cervical fixations in treating compression-extension injury with unilateral facet joint fracture: a finite element study. BMC Musculoskelet Disord. 2021;22(1):938.
71. Jia ZQ, Zhao LT, Rong XQ, Lv HW, He XJ. Letter to the editor regarding "percutaneous full-endoscopic anterior transcorporeal procedure for cervical disc herniation: a novel procedure and early follow-up study." World Neurosurg. 2018;118:385.
72. Choi KC, Ahn Y, Lee CD, Lee SH. Combined anterior approach with transcorporeal herniotomy for a huge migrated cervical disc herniation. Korean J Spine. 2011;8(4):292–4.
73. Munn Z, Barker TH, Moola S, et al. Methodological quality of case series studies: an introduction to the JBI critical appraisal tool. JBI Evid Synth. 2020;18(10):2127–33.

Publisher's Note