https://doi.org/10.48047/AFJBS.7.5.2025.1068-1088

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

Multistage Surgery for Management of Cervical Tuberculosis: a Systematic Review

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Volume 7, Issue 5, Jun 2025

Received: 13April 2025

Accepted: 02 May 2025

Published: 06 Jun 2025

doi:10.48047/AFJBS.7.5.2025.1068-1088

ABSTRACT:Background: Cervical tuberculosis (CTB) is a rare but severe form of spinal tuberculosis, often leading to progressive kyphotic deformity, spinal instability, and neurological deficits. While anti-tuberculosis therapy (ATT) remains the cornerstone of treatment, surgical intervention is often required to achieve decompression, stabilization, and deformity correction. Multi-staged surgical approaches have been proposed to optimize outcomes in complex cases. This review seeks to synthesize the latest evidence on multi-staged surgical techniques for CTB, focusing on indications, surgical approaches, clinical outcomes, and associated risks.**Methods:** We search systematically in the PubMed, Scopus, and EBSCO databases in accordance with PRISMA criteria. Inclusion criteria were: 1) Retrospective or prospective cohort, case-based design; 2) CTB patients undergoing multi-staged surgery; 3) Peer-reviewed articles. Exclusion criteria comprised irretrievable full-text articles and non-human cohorts. Risk of bias was assessed using the Newcastle-Ottawa Scale (NOS).

Results: Eight studies were analyzed qualitatively, comprising 48 patients underwent multi-staged surgery. NOS showed that six studies were qualified as high quality and low bias risk. Two studies, classified as case-based studies, lacked compatibility to be assessed. Overall, multi-staged surgery resulted in significant pain relief (MD VAS reduction from 6.8 to 1.8 points), neurological improvement (ASIA grade enhancement in 75% of patients), and kyphotic angle correction (angle reduction from 40° to 15°). Fusion rates ranged from 70% to 100%, with insignificant recurrence or implant failure in the last follow-up.

Conclusion: Multi-staged surgery is a valuable treatment option for CTB patients with severe deformity, spinal instability, children, or high infection risk. Nonetheless, it is not unequivocally better than single-staged surgery and should be utilized only in instances where the functional and biomechanical advantages surpass the extra surgical burden. Future studies should focus on long-term comparative trials to refine patient selection criteria and optimize surgical protocols for CTB management.

Keywords: Cervical Tuberculosis, Surgery, Correction, Multi-staged

Introduction

Mycobacterium tuberculosis (MTB) is the causative agent of tuberculosis (TB), a persistent infectious disease that is mostly transmitted by airborne particles from person to person[1]. In 2022, the World Health Organization (WHO) documented 10.6 million new instances of tuberculosis (TB). In regard to 1.3 million deaths were attributed to tuberculosis, which included 167,000 cases of TB/HIV co-infection. This designates tuberculosis as the second major cause of death from infectious diseases worldwide[2]. Therefore, it persist to be a major global public health concern and ranks among the top causes of mortality from infectious diseases across the globe[3].

Musculoskeletal sites are frequently reported for extrapulmonary tuberculosis, with over 50% of musculoskeletal TB cases affecting the spine[4,5]. Cervical tuberculosis (CTB) constitutes just 3–5% of spinal tuberculosis, rendering it very uncommon in relation to thoracolumbar spinal tuberculosis[6-8]. However, the progressive onset of the condition, the limited cross-sectional diameter of the cervical spinal canal, along with the potential for delayed diagnosis, can result in considerable neurological complications and cervical instability in instances of CTB. Therefore, it is crucial to achieve early diagnosis and prompt treatment. The management of CTB may involve a range of strategies, including anti-tuberculous therapy (ATT) as a mainstay therapy and surgical intervention. While ATT remains the primary treatment for tuberculosis, patients with CTB who received ATT alone suffered an average increase of 15° in malformation progression, with 3% to 5% ultimately developing kyphosis exceeding 60 degrees [9,10]. A significant kyphotic curvature of the spine can cause considerable aesthetic and potentially leading to issues such as costo-pelvic impingement, secondary cardiovascular and respiratory complications, and delayed onset of paraplegia [10,11]. The high incidence of deformity and paraparesis (15 to 30%) have posed to be a significant concern, despite the fact that mortality rates following CTB have decreased with the use of an effective antibiotic regimen to as low as 3%[12,13].

Surgical intervention for spinal tuberculosis is necessary according to absolute, relative, and extended criteria. The necessity of decompression is implied by absolute indications in the presence of significant neurological impairments, such as bladder or bowel incontinence, or when neurological symptoms persist or worsen despite 3 to 4 weeks of medical treatment. Stabilization is necessary for juvenile patients exhibiting positive spine-at-risk indicators and in instances of multi-level or pan-vertebral pathology. An open biopsy is used when a percutaneous biopsy does not yield sufficient tissue samples or when the diagnosis remains ambiguous. Debridement is essential for extensive or persistent abscesses, lack of symptom remission or advancement despite 4 to 6 weeks of medical therapy, and probable drug-resistant infections. Relative criteria for surgery encompass kyphosis more than 30 degrees, considerable vertebral loss, and severe spinal canal damage in patients exhibiting normal neurological function. Prolonged indications advocate for surgical intervention in older individuals to facilitate early ambulation and for all patients exhibiting neurological impairments[13-16].

Numerous methodologies exist for CTB surgery, including anterior, posterior, combination anterior-posterior, and minimally invasive surgery (MIS), each with distinct advantages and disadvantages[13-16, 32-35]. Furthermore, surgical procedures may be classified as single-stage or multi-stage based on individual indications.

Despite the magnitude of problems caused by cervical tuberculosis, there are few literatures regarding this topic, thus ensuring our novelty of research. To the best of our knowledge, there are no systematic reviews regarding multiple staged surgery for cervical tuberculosis. This study aims to systematically synthesize previous study about the indication, pros and cons, approach, and outcome regarding multi staged surgery for CTB.

Material and Methods

The present research was carried out in adherence with the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) checklist guideline[18], and the protocol was recorded on PROSPERO (CRD420251030446).

Search Strategy

This study carried out a thorough search of available literature to discover a full, peer-reviewed publication assessing multistage corrective procedures for cervical TB by three independent reviewers (R.E, D.S, and J.S). In case of disagreement, three reviewers solved it through a discussion, if there is no agreement, the senior author (R.E) rendered the final decision. The literature was searched from 1 January 2014 to 31 December 2024 through PubMed (6), Scopus (194), and EBSCO (52) using Boolean method with the following keywords: cervical tuberculosis and surgical technique. The detailed information was shown in **Table 1.**

Dabatase	Keywords	Searching Result
Pubmed	cervical tuberculosis[Title/Abstract] AND surgical technique[Title/Abstract]	6
Scopus	cervical tuberculosis AND surgical technique	194
EBSCO	cervical tuberculosis AND surgical technique	52

Table 1. Search strategy result.

Inclusion and exclusion criteria

This study adapted the PICOS model for selection of included literature. The population (P) was patient with CTB presenting with kyphotic deformity, spinal instability, progressive neurological deficits, or failure of conservative management. The intervention (I) was multi-staged surgical correction, including staged anterior debridement, posterior stabilization, and/or reconstruction, aimed at deformity correction, spinal stability, and neurological recovery. The comparison (C) was multistage surgery for cervical tuberculosis (indication, pros and cons, approach). The outcomes (O) including kyphotic angle or cobb angle, Visual Analog score (VAS), American Spinal Injury Association (ASIA) grade, Erythrocyte Sedimentation Rate (ESR), and radiological assessment. The study design (S) of this systematic review is retrospective cohort or prospective cohort or case report or case series.

The inclusion criteria contained

1. Retrospective cohort studies, case reports, and case series;
2. Patients diagnosed with CTB exhibiting kyphotic deformity, spinal instability, progressive neurological deficits, or refractory to conservative treatment;
3. Articles published in peer-reviewed journals; and

4. Studies involving multi-stage surgical interventions.

Exclusion criteria comprised:

1. Articles for which full-text versions were unavailable and
2. Non-human clinical trials.

Additionally, reviewers excluded narrative reviews, systematic reviews, meta-analyses, non-comparative studies, in vitro and in vivo experimental research, technical reports, editorials or responses, scientific posters, study protocols, and conference abstracts.

Risk of bias assessment

The Newcastle Ottawa Scale (NOS) was employed to evaluate the risk of bias (ROB) and the quality of the literature incorporated in this study. The scoring system ranges from 0 to 9, where higher scores reflect a lower risk of bias and greater quality. Scores between 7 and 9 are typically regarded as high quality, while those scoring between 4 and 6 are seen as having a moderate risk of bias. Scores from 0 to 3 indicate a high risk of bias. The NOS serves as a critical assessment instrument designed to gauge the potential for bias within observational studies. The framework encompasses four dimensions for evaluating the risk of bias. (i) selection bias, (ii) performance bias, (iii) detection bias, and (iv) information bias[19].

Ethical statement

This study utilized a systematic search and collection of publicly available literature data and did not include any human or animal participants. Therefore, the use of this data did not raise any ethical concerns and was exempt from ethics committee approval.

Result

Literature search

We conducted screening to report pertinent results adhering to the pre-established inclusion and exclusion criteria. Our focus was on complete articles that satisfies these criteria and then performed data extraction. **Figure 1** illustrates that a total of 252 studies were identified using our search strategy, after which duplicates were removed, and non-English language studies were excluded. Subsequently, we excluded 109 studies based on title and abstract review, resulting in

43 papers remaining for consideration. Twenty-three papers could not be fully retrieved, resulting in 20 being available for full-text analysis. Upon reviewing the full texts, only 8 studies were included.

Characteristics of included literature

The characteristics of the literature included can be found in **Table 2**. The total number of patients included in this study is 240, with 48 patients (20%) underwent multistage surgery. All literature was published between 2014 and 2024, among all studies 6 were retrospective studies (75%) and the rest were case report and case series.

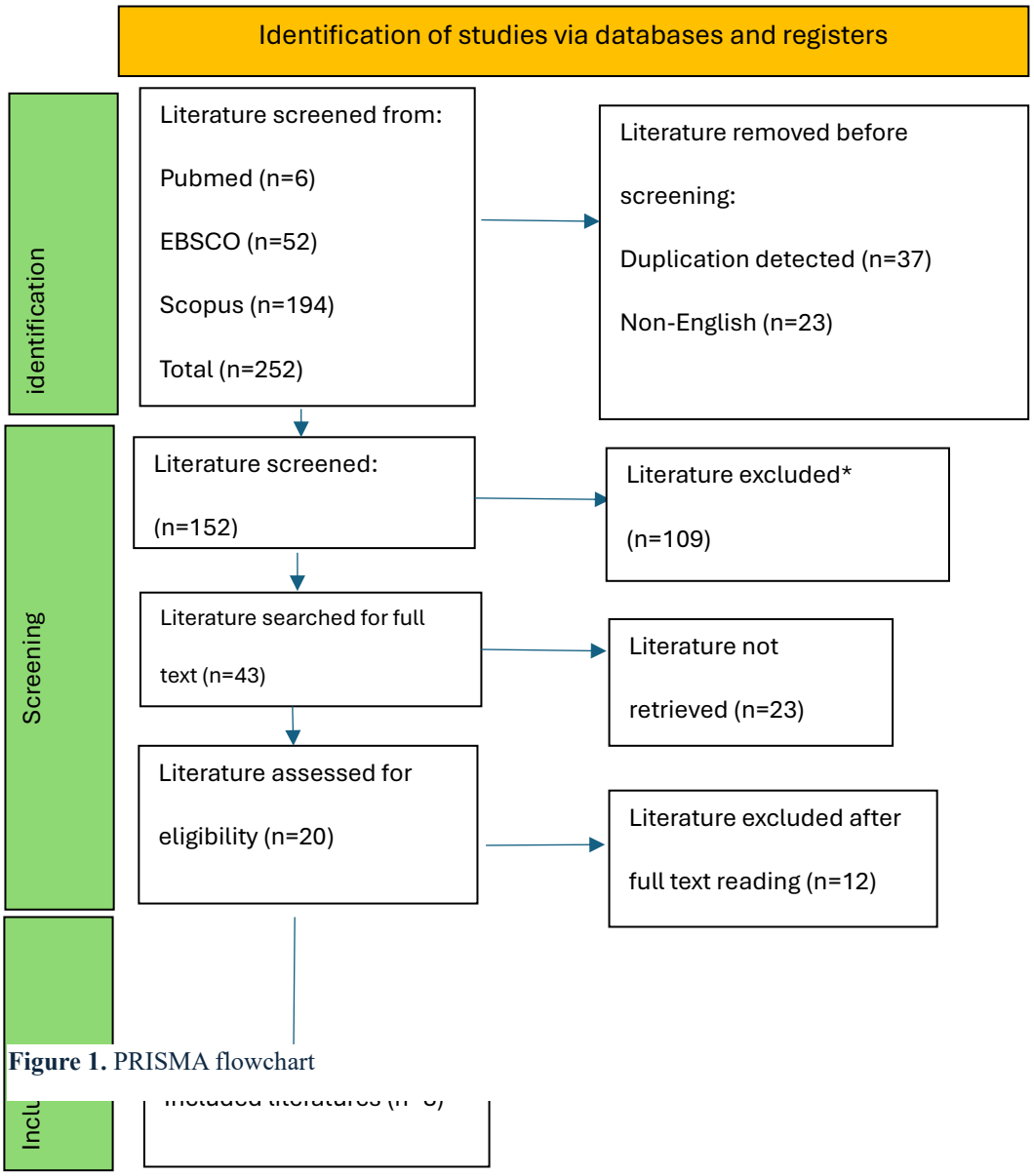

Figure 1. PRISMA flowchart

Risk of Bias analysis

Sum of nine studies were analyzed (**Table 3 and Figure 2**), with six studies receiving a valid Newcastle-Ottawa Scale (NOS) score. All (100.0%) of these studies were regared as low risk of bias with high methodological quality, indicating robust study designs and reliable findings. No studies fell into the moderate risk (0.0%) or high risk (0.0%) categories, suggesting an overall high-quality evidence base. Study by Yin *et al*., and Liao *et al*., achived highest score of 8. Additionally, three studies (25%) were case reports or case series, which are inherently not applicable for NOS scoring. While these descriptive studies provide valuable clinical insights, they lack comparative elements necessary for rigorous risk of bias assessment.

No	Author (Year)	Study design	Sample size (n)	Age , years (mean ± SD)	Sex (male/female)	Intervention / Surgical Approach	Multistage surgery
1	Hou *et al*., (2015)[20]	Retrospective Study	Total n=11 N=2 → ATT N=9 → CT debridement, 2 patients underwent second stage posterior instrumentation	33.3 ± 16.5	8M/3F	Stepwise therapy: • ATT • CT-guided percutaneous drainage • Posterior fixation	Indications. Atlantoaxial dislocation or subluxation following CT debridement and progressive compression of the spinal cord following CT debridement
2	Zeng *et al*., (2016)[21]	Retrospective Study	Total n =12 Single stage n=9 Second stage n=3	10.6 ± 2.0	7M/5F	360-degree cervical arthrodesis, and anterior debridement & decompression	Imdicaiton:Poor constitution, weak general condition, correction and preventing progression of kyphotic angle
3	Ermawan *et al*., (2020)[22]	Case report	Total n=2, both received multistage surgery with cages or without cages	NR	0M/2F	Two-stage reconstruction surgery using expandable & non-expandable cages • Anterior debridement and posterior fusion • Posterior stabilization	Indication: Repairing kyphotic angle
4	Yin *et al*., (2018)[9]	Retrospective Study	Total n=78 Anterior group n= 37 Combined group n=29 (single stage n: NR; multistage n:NR) Posterior group n=12	36.9 ± 12.8	43M/35F	• Anterior-only • Posterior-only • Combined Anterior-Posterior surgery (one stage and two stage)	Indication: depending on patient condition, explanation NR
5	Wang *et al*., (2013)[23]	Retrospective Study	Total n=66 n=40 → conservative n= 22 → single stage anterior debridement and bone grafting n=2 → multistage	51.3 ± 16.0	48M/24F	Graded management: • Anterior debridement and bone graft • Combined anterior allogenic bone block and posterior screw/rod (multistage)	Indication: suboptimal nutritional condition and elevated susceptibility to infection, multisegmented anterior decompression in the presence of osteoporosis or bone deterioration; partial (three-segment) or complete four-segment corpectomy; and in instances where stabilization poses challenges

Table 2. Study Characteristics included literature. Abbreviation: SD: standard deviation; NR: not reported; ATT: anti tubercular therapy; ESR: erythrocyte sedimentation rate ; VAS: visual analog scale; CT: computed tomography; ASIA: American spinal injury association; mm: millimeter; h: hour; CRP: c-reactive protein; ODI: Oswestry disability index; NA: not applicable.

No	Follow-up duration (mean ± SD)	Outcome measure	Key findings	Level of evidence
1	60 ± 6.3 months	ESR, VAS score, Radiologic assessment	Mean VAS score significantly decreased from 8.36 to 2.55 points; 7 out of 9 (77.8%) achieved bone union; Mean ESR decreased from 50.45 to 10.27 mm/h ; no case of recurrence and implant failure	IV
2	34.3 ± 8.6 months	Kyphosis angle, VAS score, ASIA grade, ESR	Mean VAS score significantly decreased from 6.6 ± 1.6 to 0.3 ± 0.5 at final follow-up; ESR normalized 8.5 ± 0.6 mm/h 3 months postoperatively; final follow-up post operative kyphosis angle: -4.3 ± 4.7, with minimal loss of correction; ASIA score improved in all non-grade E patients, while all grade E patients remained normal	III
3	NR	Cobb angle, fusion rate, neurological status	Both patients had cobb angle improvement, 44 to 18 degrees and 14 to 3 degrees. CT scans confirm successful bone fusion, no neurological deficit was observed. . Both expandable and non-expandable cages provided satisfactory outcomes	V
4	41.2 ± 7.2 months	VAS score, ESR,ASIA grade, Kyphosis angle	VAS score significantly improved in all groups; Final follow up cobb angle remains stable. Significant recovery was observed in ASIA grade. All three surgical approaches were viable: combined approach best for severe kyphosis,	III
5	38.2 ± 6.2 months	ASIA grade, X-ray, CT evaluation	All patients showed neurological improvement, with a majority reaching grade E, CT scans confirmed stable bone fusion. One case of delayed union and abscess formation	III

Table 2. Cont.

No	Author (Year)	Study design	Sample size (n)	Age, years (mean ± SD)	Sex (male/female)	Intervention / Surgical Approach	Multistage surgery
6	Liao *et al*., (2019)[24]	Retrospective Comparative Study	Total n= 41 Single stage n=23 Multistage n=18	42.9 ± 12.2	25M/16F	Long posterior instrumentation with/without laminectomy, + anterior debridement in single or multistage surgery	Indication: clinical symptoms, and blood and imaging examinations showed aggravation of spial TB after first surgery
7	Al-Sebai *et al*., (2001)[25]	Case series	Total n=14 Single stage n = 6 Multistage n = 8	23.7 ± 14.0	5M/9F	Anterior debridement with/without decompression and grafting (single stage) Posterior fusion and instrumentation (multi)	Indication: instability which is caused by progressive deformity, involving three or more vertebrae, or destruction of anterior and posterior columns
8	Bunmaprasert *et al*., (2015)[26]	Retrospective Study	Total n=16 Single stage n=3 Multistage n=13	13M/5F	43M/35F	ATT + anterior debridement and corpectomy in multistage or posterior fusion alone	NR

Table 2. Cont.

No	Follow-up duration (mean ± SD)	Outcome measure	Key findings	Level of evidence
6	35 ± 10.7 months	ODI, VAS, ESR, CRP, Cobb angle, Frankel scores	No significant difference in neurological recovery (Frankel score) between two groups. Significant pain reduction in both groups. Significant improvement in ODI scores. Significant correction of cobb angle.	III
7	40 ± 10.3 months	Kyphosis angle, Neurological function (Frankel), Bone fusion	All patients showed neurological improvement, two staged procedures provide superior kyphosis correction, all patients achieved bone fusion within 4 to 9 months.	III
8	12.8 months	Nurick's Disability Index, Pain Reduction, Fusion Rate	70& patients that surgically treated showed significant neurological improvement, conservative treated patient had a slower recovery, bone fusion achieve within 3-12 months for surgery and 12- 15 months conservatively. All patients showed a pain reduction	III

Table 2. Cont.

Authors	Study Design	Selection Score (0-4)	Comparability Score (0-2)	Outcome Score (0-3)	Total NOS Score	Risk of Bias & Quality
Hou *et al.,*	Retrospective study	3	1	2	6	Low risk of bias - High quality
Zeng *et al.,*	Retrospective Study	4	1	2	7	Low risk of bias - High quality
Yin *et al.,*	Retrospective Study	4	2	2	8	Low risk of bias - High quality
Wang *et al.,*	Retrospective Study	4	1	2	7	Low risk of bias - High quality
Al-Sebai *et al.,*	Case Series	NA	NA	NA	NA	NA
Bunmaprasert *et al.,*	Retrospective Study	4	1	2	7	Low risk of bias - High quality
Liao *et al.,*	Retrospective Comparative	4	2	2	8	Low risk of bias - High quality
Ermawan *et al.,*	Case report	NA	NA	NA	NA	NA

Table 3. NOS score of included literatures. Abbreviations: NA: Not applicable.

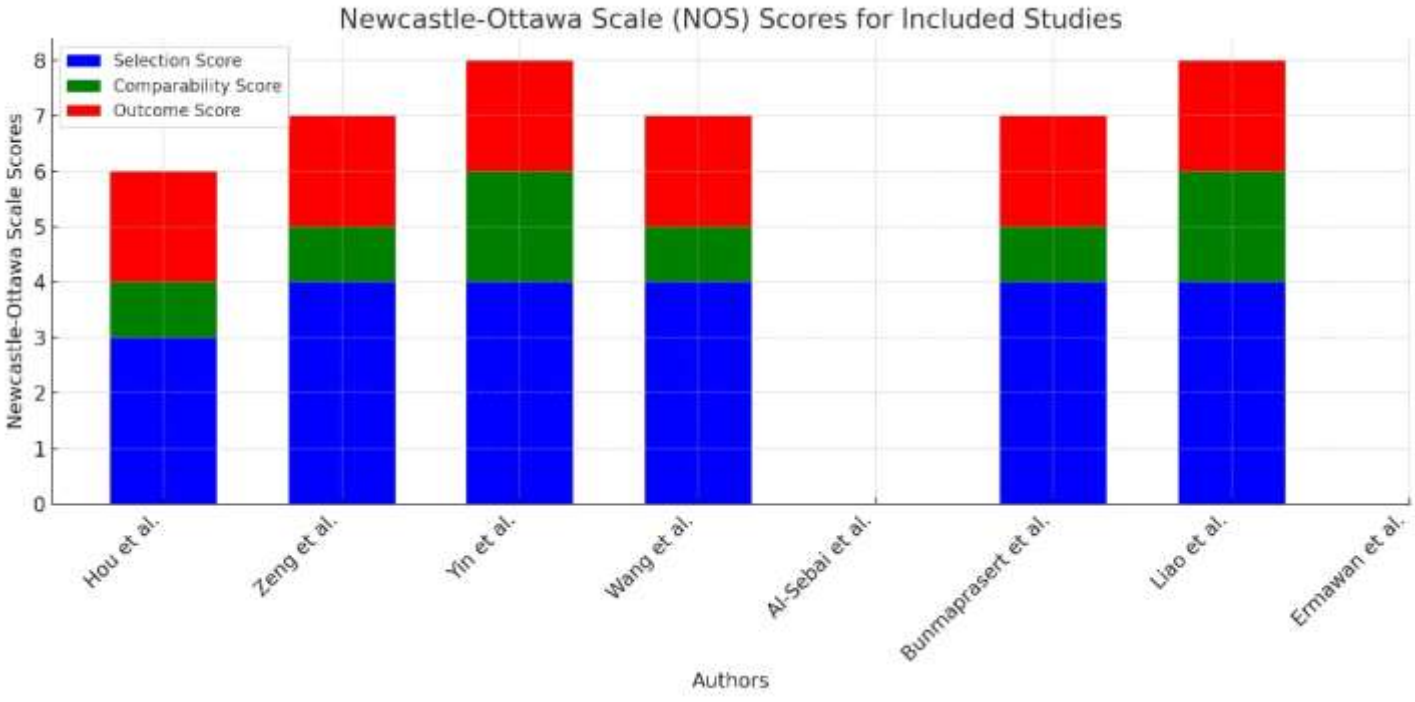

Figure 2. Bar-graph NOS score of included studies

Outcome summary

Multi-staged surgery is particularly beneficial for severe kyphotic deformities requiring gradual correction, as noted by Ermawan *et al*., Yin *et al*., Wang *et al*., and Bunmaprasert *et al*.[9,22,23,26] It is also recommended for cases of atlantoaxial dislocation post-debridement to prevent spinal cord compression (Hou *et al*., Liao *et al*.)[20,24] and for patients with high infection risk or multi-segmental involvement (Wang *et al*., Al-Sebai *et al*.).[9,25] The approach enhances spinal stability, minimizes infection risks, and optimizes neurological recovery (Zeng *et al*., Al-Sebai *et al*.)[21,25], while clinical outcomes show significant pain relief, improved neurological function, and effective kyphotic angle correction (Hou *et al*., Yin *et al*., Zeng *et al*.).[9,20,21] Despite some studies suggesting comparable outcomes with single-stage surgery (Liao *et al*., Zeng *et al*.)[21,24], others strongly support the multi-staged approach for severe instability and progressive deformity (Al-Sebai *et al*., Ermawan *et al*.).[22,25] These findings emphasize the need for individualized patient selection and standardized surgical protocols.

Discussion

Multi-staged surgery plays a critical role in the management of cervical tuberculosis (CTB), particularly in cases presenting severe kyphotic deformity, spinal instability, and progressive neurological deficits [8,9,24-32]. Multi-staged procedures typically involve an initial stage of anterior debridement and decompression, followed by posterior stabilization at a later stage. Some protocols also include additional anterior reconstruction if necessary. This staged approach allows for a stepwise correction of deformity while ensuring that the patient is optimized for subsequent surgeries The decision to opt for a multi-staged approach is based on several clinical factors, including the extent of vertebral destruction, the presence of multi-segmental involvement, and the overall health status of the patient[8,9,24-32] This approach is particularly beneficial in cases of extensive vertebral destruction, severe kyphosis, or when multiple vertebral segments are involved[8-10]. Studies comparing single-stage and multi-staged surgery have demonstrated that while both approaches can achieve satisfactory outcomes, multi-staged surgery allows for a more controlled correction process, reducing the risk of intraoperative neurological compromise[9,15,24-32].

Studies have demonstrated that multi-staged surgery is particularly indicated in cases where kyphotic deformity is severe and requires gradual correction, as seen in reports by Ermawan *et al*., Yin *et al*., Wang *et al*., and Bunmaprasert *et al* [9,22,26,]. This approach is also preferred in cases with atlantoaxial dislocation or subluxation post-debridement, necessitating staged stabilization to prevent progressive spinal cord compression. Additionally, multi-staged surgery is beneficial for patients with poor nutritional status, high infection risk, and multi-segmental anterior decompression needs, as outlined by Wang *et al*. and Al-Sebai *et al* [9,25]. Moreover, patients who experience failure of first-stage surgery to adequately control infection or restore stability may require a second-stage intervention, as emphasized by Liao *et al* [24]. The need for multi-staged surgery is further reinforced in cases of extensive anterior and posterior column destruction requiring stepwise stabilization, as reported by Al-Sebai *et al*. and Bunmaprasert *et al* [25,26].

Upadhyay et al. presented a comparative review examining the short-term and long-term outcomes of two surgical techniques involving anterior debridement paired with either autograft or allograft bone restoration[29]. To enhance the deformity angle, the findings indicated

that anterior radical surgery is more effective than pure debridement surgery. Numerous authors have suggested that in pediatric cases, a combination of anterior plate with debridement, decompression, titanium mesh cage, or autograft/allograft bone is advisable[32-35]. In truth, anterior surgery provides a straightforward method for sufficient decompression, alongside effective stabilization and reconstruction of the cervical spine. Nonetheless, a stand-alone anterior approach is limited to addressing immediate concerns, overlooking the reality of the uneven growth potential between anterior and posterior elements over the long term. Consequently, certain authors advocate for supplementary posterior instrumentation to restrict posterior growth for the sake of balance[25,26,34,35.] Crucially, in addition to this, posterior fixation is required for the correction and maintenance of kyphosis in the therapy of CST.

The functional role of multi-staged surgery is primarily centered on achieving long-term spinal stability, minimizing infection risk, and optimizing neurological recovery. This approach allows for progressive correction of severe kyphotic deformities while minimizing excessive stress on adjacent vertebrae, a key advantage highlighted by Zeng *et al*. and Al-Sebai *et al*[21,25]. Al-Sebai et al.,[25] also recommended that The implementation of second stage posterior fusion with instrumentation is expected to facilitate neurological recovery, as experimental evidence suggests that rigid stabilization of the spine enhances the chances of such recovery. Which occurred in the ten patients with a neurological deficit in their study. Sequential infection control through staged debridement before definitive stabilization also plays a crucial role in improving clinical outcomes, as demonstrated in studies by Hou *et al*. and Liao *et al.*[20,24] Additionally, the adaptability of a multi-staged approach provides flexibility in surgical planning, particularly in cases where initial interventions fail to provide sufficient correction or symptomatic relief.

Clinical outcomes following multi-staged surgery have been consistently positive across multiple studies, with significant improvements in pain relief, neurological function, deformity correction, and fusion rates. Pain scores, as measured by the Visual Analog Scale (VAS), have shown marked reductions, with post-surgical pain levels decreasing from an average of 6–8 preoperatively to 0.3–2.5 postoperatively, as reported by Hou *et al*., Yin *et al*., Zeng *et al*., and Liao *et al* [9,20,21,24]. Neurological improvement has been well-documented, with all studies showing advancements in ASIA or Frankel scores, with some patients recovering from severe neurological impairment to near-normal function, as evidenced by Yin *et al*., Bunmaprasert *et al*., and Wang *et al.,* [9,23,26]. Furthermore, studies have consistently

demonstrated that multi-staged surgery effectively stabilizes the kyphotic angle and achieves bone fusion with minimal loss of correction over time, as noted by Zeng *et al*., Ermawan *et al*., and Al-Sebai *et al* [21,22,25]. Fusion rates among patients undergoing multi-staged surgery range between 70% and 100%, with no significant recurrence or implant failure observed in long-term follow-ups, reinforcing its effectiveness as a definitive management strategy, as reported by Hou *et al*., Al-Sebai *et al*., and Wang *et al*.[20,23,25]

The consensus among included studies underscores the importance of a multi-staged approach in selected patient populations, though variations in practice exist. While some studies, such as those by Liao *et al*. and Zeng *et al*.,[21,24] have demonstrated comparable outcomes between single-stage and multi-stage surgeries in terms of neurological recovery, others, including Al-Sebai *et al*. and Ermawan *et al*.,[22,25] strongly advocate for multi-staged surgery in cases of severe instability and progressive deformity. Furthermore, Bunmaprasert *et al*. emphasized the necessity of anterior debridement in cases with extensive epidural abscesses, reinforcing the tailored approach needed in surgical decision-making. These differences highlight the need for individualized patient assessment to determine the most appropriate surgical strategy[26]

Despite its advantages, multi-staged surgery also presents certain drawbacks. One of the primary disadvantages is the longer total recovery time due to multiple hospitalizations, which can place a substantial burden on both the patient and healthcare system. Financially, multi-staged procedures can be more expensive compared to single-stage surgeries, which may limit accessibility for some patients. Additionally, undergoing multiple surgical interventions increases the overall surgical risk, including anesthesia-related complications and the possibility of perioperative infections. Postoperatively, patients undergoing multi-staged surgery require meticulous monitoring, as delayed fusion may necessitate prolonged bracing and rehabilitation. These challenges highlight the need for careful selection of patients to ensure that the benefits of a multi-staged approach outweigh the associated burdens

This investigation is constrained by several limitations. The inclusion of studies was limited, with merely eight studies fulfilling the criteria, potentially impacting on the broader applicability of the results. The variability among the included studies regarding surgical techniques, follow-up duration, and patient selection criteria complicates direct comparisons. Additionally, most of the studies analyzed were retrospective, which naturally introduces a risk

of bias and restricts the capacity to determine causality. Furthermore, although multi-staged surgery has shown potential for enhanced outcomes in certain cases, the absence of standardized protocols for patient selection and surgical staging hinders the ability to replicate findings across various institutions. A further limitation is the lack of long-term follow-up data in certain studies, which complicates the assessment of the sustainability of surgical outcomes beyond a two-year period. Ultimately, the economic and logistical aspects related to multi-staged surgery were not thoroughly examined in the studies reviewed, which may influence clinical decision-making, especially in settings with limited resources. Future investigations ought to concentrate on prospective studies employing standardized methodologies to more accurately delineate the role of multi-staged surgery in CTB and enhance clinical guidelines.

Conclusion

In conclusion, multi-staged surgery remains a valuable treatment option for complex CTB cases, particularly those characterized by severe kyphosis, instability, or high infection risk, pediatric cases. It offers superior deformity correction, pain relief, and neurological improvement when appropriately indicated. However, it is not universally superior to single-stage surgery and should be reserved for cases where the functional and biomechanical benefits outweigh the additional surgical burden. Future research should focus on long-term comparative studies to refine patient selection criteria and optimize surgical protocols, ensuring that each patient receives the most effective and individualized treatment approach.

Conflicts of Interest:

The author declares that there are no relevant conflict of interest

Source of Funding:

None

Author Contribution:

Rieva Ermawan designed the study and supervised the experiment; Dhanang Susilo performed the experiments; Dhanang Susilo and Hilmi Amirul Haq wrote the manuscript; M Iyad Madani provided critical reagents.

Ethical Approval:

The study did not require ethical approval because we analyze the published data and don't involve collecting new information from human or alive subjects

Informed Consent:

The study did not need informed consent because no human subjects is involved

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