CLINICAL ARTICLE

Preoperative Skull Traction, Anterior Debridement, Bone Grafting, and Internal Fixation for Cervical Tuberculosis with Severe Kyphosis

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Objective: Cervical tuberculosis (CTB) readily causes local kyphosis, and its surgical strategy remains controversial. Although some previous studies suggested that the anterior approach could effectively treat CTB, patients in these studies only suffered mild to moderate kyphosis. Therefore, little is known about whether the anterior approach can achieve satisfactory outcomes in CTB patients with severe kyphosis. This study was performed to evaluate the safety and efficacy of preoperative skull traction combined with anterior surgery for the treatment of CTB patients with a severe kyphosis angle of more than 35°.

Methods: In this retrospective study, we enrolled 31 CTB patients with severe kyphosis who underwent preoperative skull traction combined with anterior surgery from April 2015 to January 2021. Patients were followed up for at least 2 years. Clinical data, such as operative time, blood loss, and postoperative hospital stay, were collected. The clinical outcomes included American Spinal Injury Association (ASIA) spinal cord injury grade, Japanese Orthopaedic Association (JOA) score, visual analog scale (VAS) score, and related complications. The radiological outcomes included the Cobb angle of cervical kyphosis at each time point and the bony fusion state. Clinical efficacy was evaluated by paired Student's *t*-test, Mann–Whitney *U*-test, and others.

Results: Six patients had involvement of one vertebra, 21 had involvement of two vertebrae, and four had involvement of three vertebrae. The most common level of vertebral involvement was C4-5, whereas the most common apical vertebra of kyphosis was C4. The mean kyphosis angle was 46.1° ± 7.7° preoperatively, and the flexibility on dynamic extension-flexion X-rays and cervical MRI was 17.5% ± 7.8% and 43.6% ± 11.0%, respectively ($p = 0.000$). The kyphosis angle significantly decreased to 13.2° ± 3.2° after skull traction, and it further corrected to −6.1° ± 4.3° after surgery, which was well maintained at the final follow-up with a mean Cobb angle of −5.4° ± 3.9°. The VAS and JOA scores showed significant improvement after surgery. The erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP) levels normalized at 3 months after surgery. All patients achieved solid bone fusion, and no complications related to the instrumentation or recurrence were observed.

Conclusion: Preoperative skull traction combined with anterior debridement, autologous iliac bone grafting, and internal plate fixation can be an effective and safe surgical method for the treatment of cervical tuberculosis with severe kyphosis. Skull traction can improve the safety and success rate of subsequent anterior corrective surgery.

Key words: Cervical Tuberculosis; Severe Kyphosis; Skull Traction; Anterior Surgery

Introduction

Cervical tuberculosis (CTB) is rare and accounts for only approximately 3%–5% of all spinal tuberculosis cases, while it is potentially dangerous because of the relatively high incidence of severe complications.[1,2] Due to the specific conditions of the cervical spine, such as smaller canal diameter,

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greater mobility, and its location adjacent to the central nerve structure, spinal nerve roots, and vertebral artery, lesions in this region could easily cause spinal cord compression.[3,4] In addition, spinal tuberculosis usually invades the anterior and middle columns of the spine, while the posterior column is rarely involved. Considering the cervical lordotic alignment and the weight of the head, CTB readily causes local kyphosis. Moreover, the axial loads tend to cause additional kyphosis by means of the application of the axial load through an arm-induced bending movement, which may be said to mean "kyphosis begets kyphosis."[5,6] In some severe cases, kyphosis can result in dysphagia, worsening spinal cord compression, and subsequent quadriplegia.[7] Meanwhile, it can also be accompanied by retropharyngeal abscess, which might cause compression over the esophagus and trachea and even respiratory depression.[8]

Specific anti-tuberculosis chemotherapy is still the primary treatment. However, nonsurgical treatment might not always be effective for all causes, especially in those with neurological deficits and spinal deformities. When CTB causes major vertebral body destruction and is associated with significant kyphosis, local kyphosis remains even if the infection is successfully cured, which might limit the normal function of the neck, cause mechanical neck pain, and thereby significantly impair patients' quality of life.[9,10] Therefore, relatively active surgical treatment is required for patients with CTB. Several surgical methods, including anterior, posterior, and combined anterior–posterior surgery, have been reported in the treatment of CTB.[11–18] Since the anterior approach allows for direct removal of the lesion and restoration of spinal stability under visualization, it has become the most common surgical approach, and its satisfactory mid- or long-term outcomes have been reported in many studies.[11–14,18] However, when CTB is accompanied by significant kyphosis (CTBK), whether anterior surgery alone can provide adequate stability to achieve a good correction rate and prevent loss of correction is a major concern. Therefore, some surgeons recommend additional posterior fixation via combined anterior–posterior surgery to obtain a better outcome in these patients.[16,17] According to their reports, neurologic function was significantly improved through combined surgery, and the correction rate was more than 100%, which maintained well at the final follow-up (loss of correction less than 1°). However, this surgery method usually accompanied with larger blood loss (100–450 mL), and longer operation and hospitalization time (160–300 min and 10–20 days, respectively). Moreover, some patients even have to undergo two-stage surgery due to poor conditions and intolerance to continuous trauma, which creates potential risks and increases medical costs. Therefore, anterior surgery might be an advantageous alternative for the treatment of CTBK, which could effectively avoid the above problems in combined anterior–posterior surgery. However, the majority of previous studies on anterior surgery for CTB were not associated with severe kyphosis (the Cobb angle was usually less than 35°), there is still little known about whether the anterior approach could achieve satisfactory outcomes in patients with CTBK. In our hospital, cervical tuberculosis patients whose Cobb angle of kyphosis was greater than 35° were treated with preoperative skull traction followed by anterior debridement, autologous iliac bone grafting, and internal plate fixation. Therefore, the purpose of this study was (1) to evaluate the safety and efficacy of preoperative skull traction combined with anterior surgery for the treatment of cervical tuberculosis with significant kyphosis; and (2) to explore its feasibility and share surgical experiences.

Methods

This study was approved by the Ethics Committee of the West China hospital (No. 2021–271), and informed consent for participation was obtained from all patients. Patients with CTB who underwent surgical treatment at our hospital from April 2015 to January 2021 were identified for inclusion. The inclusion criteria were (1) lower cervical tuberculosis that involved vertebrae from C3 to C7; (2) Cobb angle of kyphosis greater than 35°; (3) age between 20 and 60 years; and (4) minimum follow-up period of more than 2 years. The exclusion criteria were as follows: (1) kyphosis secondary to trauma, neoplastic disease, congenital or neuromuscular deformity, systemic arthritis such as ankylosing spondylitis and rheumatic arthritis; (2) old cervical tuberculosis with segmental ankylosis; (3) severe osteoporosis ($T < -2.5$); and (4) history of cervical surgery. Overall, 42 patients with CTB who underwent surgical treatment within this time period were identified, while only 31 patients were finally included in this study due to the inclusion and exclusion criteria. The diagnosis was based on medical history, clinical symptoms, laboratory test results (increased erythrocyte sedimentation rate [ESR] and C-reactive protein [CRP]), and radiological findings (cervical X-ray, computed tomography [CT], and magnetic resonance imaging [MRI]) and was confirmed by histological examination, acid-fast staining, or polymerase chain reaction of tissue removed at surgery. Indications for surgery included (1) persistent neck and/or radicular pain resistant to conservative treatment or related to instability; (2) progressive neurological deficit and/or kyphosis; and (3) significant local kyphosis (>35°).

Preoperative Procedure

Patients enrolled in this study all received the standard HREZ (isoniazid, rifampicin, ethambutol, pyrazinamide) anti-tuberculosis chemotherapy regimen, consisting of isoniazid (300 mg/day), rifampicin (450 mg/day), ethambutol (750 mg/day), and pyrazinamide (750 mg/day) for at least 4 weeks before surgery. General nutritional treatment was also given throughout chemotherapy. Preoperative skull traction on mild hyperextension position was performed in all patients to partially correct the kyphosis and to improve the correction rate. Bedside X-rays were reviewed on the first day after traction and every 2 days thereafter. Surgical procedures were performed when kyphosis improved by more than 50% or no longer improved after traction. Finally, the

traction time lasted for 3–7 days, with an average of 4.5 ± 1.1 days, and the traction weight started at 1 kg, which increased gradually based on individual tolerance and up to a final weight of 3–6 kg, with an average of 4.8 ± 1.6 kg.

Surgical Procedure

Surgery was performed under general endotracheal anesthesia, and all patients were monitored with intraoperative motor and somatosensory evoked potentials. The patients were placed in a supine position with skull traction and a weight of 2–3 kg during the operation, and the Smith-Robinson approach was performed. The paravertebral and retropharyngeal abscesses were identified and drained where exploratory aspiration with an empty needle was sometimes used. As much necrotic tissue as possible was removed until healthy bone was observed. The spinal cord was decompressed carefully. Then, screws for the distraction system were inserted into one healthy vertebra above and one below, and distraction was performed via a Caspar distractor to restore the affected vertebral height and correct the local kyphosis. After confirming the good pulsation of the dura theca and adequate decompression, the height of the vertebral gap was measured, and autologous iliac bone of the appropriate size was embedded and fixed with an anterior cervical plate. After C-arm fluoroscopy identified the correction of kyphosis and implant position, a drainage tube was placed, and the incision was closed.

Postoperative Procedure and Follow-Up Index

The drainage was pulled out once the drainage volume was less than 30 mL/24 h. The standard HREZ anti-tuberculosis drugs were continued for 6 months, which was followed by HRE for another 9–12 months (6HERZ/9-12HRE). In addition, routine medical treatments were performed, including prophylactic antibiotic administration, nutritional support, mannitol dehydration, and nerve nutrition. The patients usually sat with a cervical orthosis on the first or second postoperative day and were then encouraged to stand or walk on the third postoperative day. All patients were braced in a cervical orthosis for 3 months after surgery.

Clinical demographic data, operative time, blood loss, and postoperative hospital stay were collected. Laboratory tests (ESR and CRP) were used to monitor TB activity. The American Spinal Injury Association (ASIA) spinal cord injury grade, Japanese Orthopaedic Association (JOA) score, and visual analog scale (VAS) score were used to evaluate clinical outcomes. Radiological examinations (cervical X-ray, MRI, and CT) were performed to assess the bone fusion state, flexibility and correction of kyphosis. The fusion state was evaluated on CT according to the 5-grade criteria of Brantigan et al.[19] Grade 4 or 5 was defined as fused, grade 1 or 2 was defined as unfused, and grade 3 was unable to be assessed. The cervical kyphosis angle was defined as the angle between the inferior endplates of the vertebrae above and below the kyphotic segment. The Cobb angle of C2-7 was also measured. A negative angle indicates lordosis, and a positive angle indicates kyphosis. It was measured on the lateral X-ray films preoperatively, after traction, postoperatively, and at the final follow-up. The flexibility of kyphosis was evaluated on both dynamic extension-flexion X-rays and cervical MRI: X-flexibility (%) = (kyphosis angle on neutral lateral X-ray − kyphosis angle on extension X-ray)/kyphosis angle on neutral lateral X-ray × 100%; and MRI-flexibility = (kyphosis angle on neutral lateral X-ray − midsagittal of cervical MRI)/kyphosis angle on neutral lateral X-ray × 100%. Complications were recorded, including internal fixation loosening or breakage and bone graft absorption and detachment. All patients were examined at 3, 6, and 12 months after surgery and at the final follow-up (Figures 1 and 2).

Statistical Analysis

Data are presented as the means ± standard deviations. All collected data were analyzed using SPSS 23.0 software (SPSS Inc., Chicago, Illinois). Changes in ASIA grade from preoperative to final follow-up were evaluated using Wilcoxon signed ranks test. The normal distribution of continuous variables was verified by the Shapiro–Wilk test. A paired Student's *t*-test was used for variables that followed a normal distribution (changes in cervical kyphosis angle). The Mann–Whitney *U*-test was used for those not following a normal distribution (changes in JOA, VAS, ESR, and CRP). A *p*-value less than 0.05 indicated a significant difference.

Results

Demographic and Clinical Characteristics

A total of 31 patients with CTBK were enrolled in this study. There were 12 males and 19 females, with an average age of 37.5 ± 18.2 years. All patients suffered neck pain and restricted neck activity. The constitutional symptoms of TB, such as mild fever and night sweats, were present in 18 patients. Twenty-four patients were complicated by spastic quadriparesis, including numbness of extremities, difficulty holding objects, and a feeling like they were walking on cotton. Cervical radiculopathy was noted in 11 patients. The mean course of disease was 6.2 ± 1.5 months (Table 1). According to the preoperative radiological examinations, six patients had involvement of one vertebra, 21 had involvement of two vertebrae, and four had involvement of three vertebrae. The most common level of vertebral involvement was C4-5, whereas the most common apical vertebra of kyphosis was C4 (Table 2). A paravertebral abscess was present in 20 patients, and a retropharyngeal abscess with symptomatic dysphagia was observed in six patients.

Operative Information and Clinical Outcomes

The mean operative time was 136.5 ± 33.9 min (range 90–190), the mean intraoperative blood loss was 140.6 ± 39.7 mL (range 80–250), and the mean postoperative hospital stay was 6.5 ± 1.1 days (range 5–9). Eleven

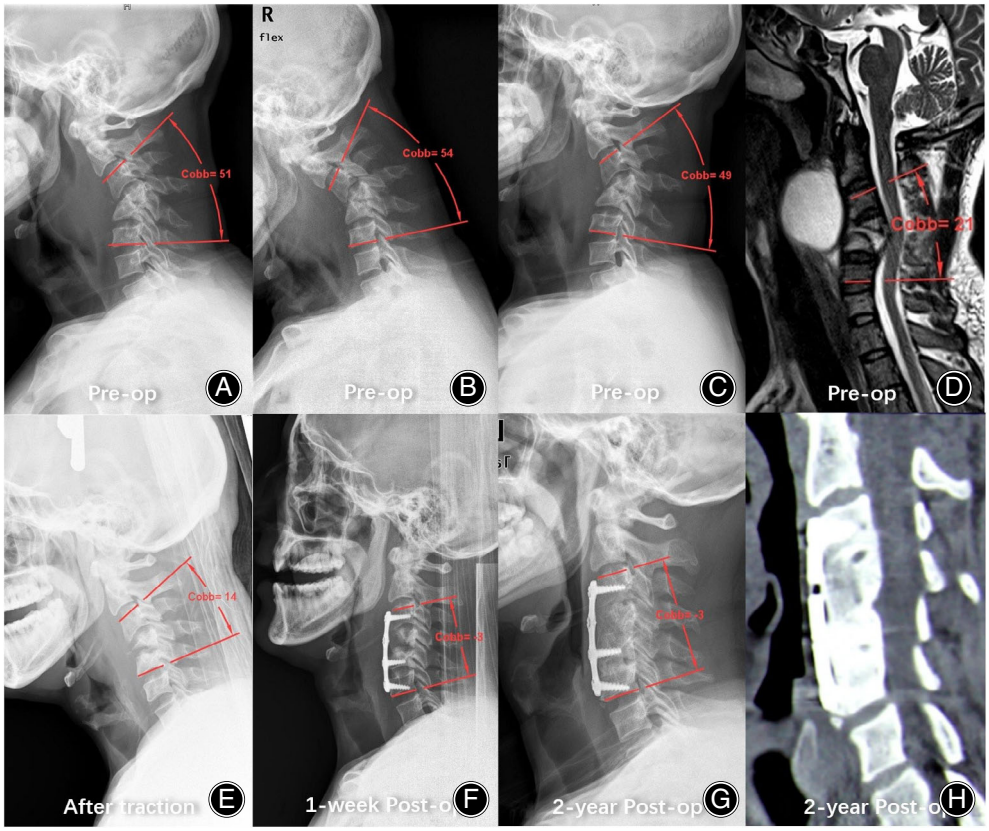

FIGURE 1 A 41-year-old male with cervical tuberculosis suffered from neck pain, spastic quadriparesis, and dysphagia due to a retropharyngeal abscess. Neutral lateral cervical spine radiograph (A) indicates cervical kyphosis of 51° at C3-6, and C4 is the apical vertebra. The kyphosis Cobb angle was 54° and 49° on flexion and extension, respectively (B, C), which indicated that the flexibility was only 3.9%. MRI showed the formation of a retropharyngeal abscess and ventral compression of the spinal cord. The Cobb angle was 21° on MRI, which indicated that the flexibility was 58.8% (D). The kyphosis angle was relieved to 14° after skull traction (E), and it was corrected to −3° after surgery (F–H). The x-ray and CT scans at the final follow-up showed that the correction was well maintained without significant loss, and solid bone fusion was finally achieved.

patients with cervical radiculopathy and six patients with dysphagia achieved immediate remission after surgery. All patients had neck pain relief and JOA score improvement. The VAS scores significantly decreased from 5.9 ± 1.2 preoperatively to 0.4 ± 0.6 at the final follow-up ($p = 0.000$), and the JOA scores significantly improved from 8.1 ± 0.9 to 12.2 ± 1.3 ($p = 0.000$). The levels of ESR and CRP normalized at 3 months after surgery in all patients. Table 3 shows the number of patients classified by ASIA grade before surgery and at the final follow-up. Patients with neurologic deficits all obtained improvement at the final follow-up examination.

Correction of Kyphosis and Bone Fusion

The mean Cobb angle of C2-7 was 26.9° ± 12.4° preoperatively, which was corrected to −10.4° ± 6.7° after surgery and maintained well until the final follow-up (−11.4° ± 5.5°). The mean preoperative kyphosis angle was 46.1° ± 7.7°, and it was 37.9° ± 6.7° on the extension X-ray with a mean flexibility of 17.5% ± 7.8%. However, on the mid-sagittal cervical MRI, it was 25.9° ± 6.7°, which indicated greater flexibility than that on extension X-ray (43.6% ± 11.0% vs. 17.5% ± 7.8%, $p = 0.000$). The kyphosis significantly reduced to 13.2° ± 3.2° with a mean correction rate of 71.3% ± 4.7% after skull traction, and it further corrected to −6.1° ± 4.3° after surgery, which was maintained well at the final follow-up with a mean Cobb angle of −5.4° ± 3.9° without significant loss (0.7° ± 1.1°). The final correction rate was 113.1% ± 10.3% (Table 4).

Bone fusion was achieved in all patients by the final follow-up, which was confirmed by two independent surgeons based on the above criteria of radiological fusion. The average fusion period was 8.4 months (range 6–12 months). No cases of loosened or broken implants or absorbed or detached grafts were observed at the final follow-up. No patient suffered pseudarthrosis or proximal junction kyphosis.

Complications

The wounds all healed without infection or sinus formation. No recurrence was observed in this cohort. No neurological deterioration was observed in any patient during preoperative skull traction. Surgery-related complications occurred in two patients. One patient suffered mild dysphagia after surgery, which recovered spontaneously within 1 week postoperatively with consumption of a liquid diet. Another patient presented with leakage of cerebrospinal fluid and recovered without infection through prolonged application of drainage and upgrading the antibiotic to ceftriaxone. In addition, two patients suffered from harvest site pain, which disappeared 1 week postoperatively without any intervention.

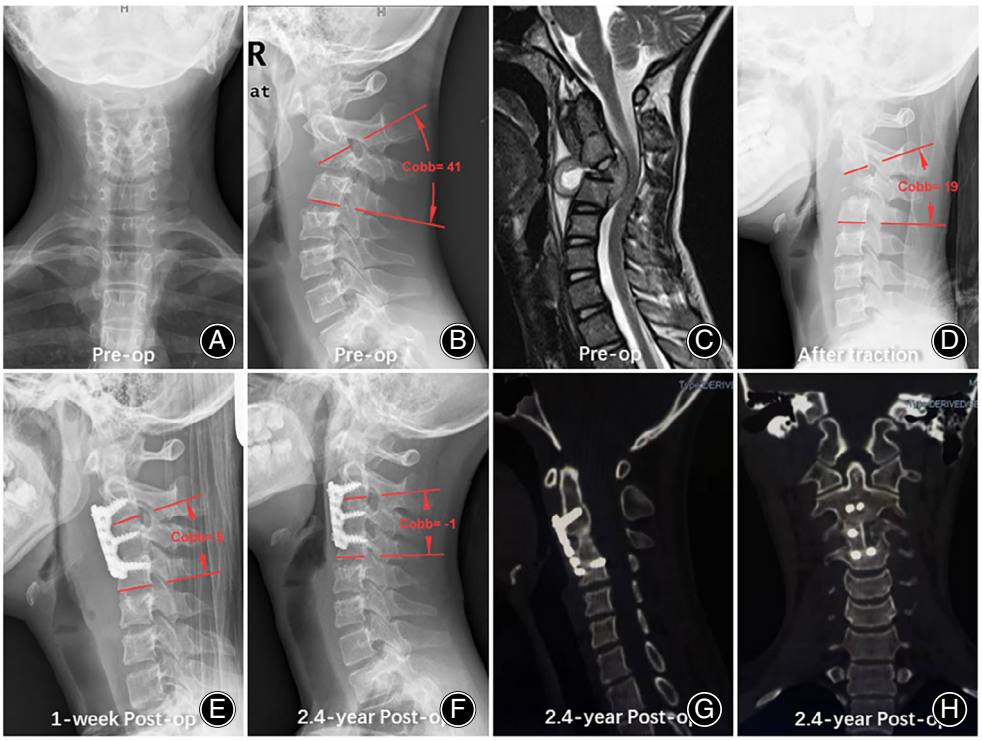

FIGURE 2 A 22-year-old female with cervical tuberculosis presented with worsening cervical pain, dysphagia, stridor, and weakness of extremities. The lateral cervical X-ray (A, B) showed severe kyphosis of 41° at C2-4, and C3 is the apical vertebra which was destroyed by the lesion. The MRI indicated clearly bony destruction located in the C3 vertebrae body, and a large retropharyngeal abscess anterior to C2-4 vertebra which also connected with the spinal canal and the lesion caused significant compression of the spinal cord (C). The lateral radiograph showed a recovering cervical alignment after skull traction, the kyphosis was relieved to 19° (D), and it was further corrected to 5° after surgery (E). The X-ray and three-dimensional CT at the final follow-up indicated the cervical sagittal alignment maintained well, and the solid bone fusion was achieved without internal fixation related complications (F–H).

Discussion

Because of cervical lordotic alignment, greater mobility, and relatively thin support by muscles and other bone structures, CTB is more likely to cause local kyphosis than thoracic and lumbar tuberculosis. Surgical treatment should be taken promptly when conservative treatment fails. In this study, we showed that preoperative skull traction combined

TABLE 1 Patients' demographic data

Parameters	$N = 31$
Age (years)	39.5 ± 15.2
Gender (M/F)	12:19
BMI (kg/m^2)	19.2 ± 3.8
Clinical features	
Neck pain	31 (100%)
Restricted neck activity	31 (100%)
Cervical radiculopathy	11 (35.5%)
Spastic quadriparesis	24 (77.4%)
Mild fever and/or night sweats	18 (58.1%)
Dysphagia by retropharyngeal abscess	6 (19.4%)
Course of disease (month)	6.2 ± 1.5
Follow-up period (month)	30.8 ± 6.9

Abbreviations: BMI, body mass index; F, female; M, male.

TABLE 2 Preoperative, intraoperative, and postoperative data of the 31 patients

Parameters	$N = 31$
Involved level (*n*)	
One level	6
Two-level	21
Three-level	4
Apical vertebral (*n*)	
C3	3
C4	14
C5	11
C6	3
Fusion level (*n*)	
Three-level	6
Four-level	19
Five-level	6
Duration of traction (days)	4.5 ± 1.1
Operative time (min)	136.5 ± 33.9
Blood loss (mL)	140.6 ± 39.7
Postoperative hospital stay (days)	6.5 ± 1.1

TABLE 3 Clinical details and outcomes of the 31 patients

Parameters	$N = 31$
ASIA grade at preoperatively (*n*)	
B	5
C	8
D	11
E	7
ASIA grade at postoperatively (*n*)	
D	5
E	26
ASIA grade at final follow-up (*n*)	
D	3
E	28*
JOA scores	
Preoperative	8.1 ± 0.9
Postoperative	10.9 ± 1.2
Final follow-up	12.2 ± 1.3†
VAS scores	
Preoperative	5.9 ± 1.2
Postoperative	2.2 ± 1.1
Final follow-up	0.4 ± 0.6‡
ESR (mm/h)	
Preoperative	61.0 ± 10.8
Post 3 month	7.4 ± 3.5§
CRP (mg/L)	
Preoperative	37.6 ± 12.8
Post 3 month	6.5 ± 2.2**

Abbreviations: ASIA, erythrocyte sedimentation rate; CRP, C-reactive protein; ESR, erythrocyte sedimentation rate; FFU, final follow-up; JOA, Japanese Orthopaedic Association; Pre-op, preoperative; Post 3 month, 3 months at postoperative; VAS, visual analog scale.; *Analyzed by Wilcoxon signed ranks test, at final follow-up compared with preoperative, $p = 0.000$, $z = -4.202$.; †Analyzed by Mann–Whitney *U*-test, at final follow-up compared with preoperative, $p = 0.000$, $z = -6.790$.; ‡Analyzed by Mann–Whitney *U*-test, at final follow-up compared with preoperative, $p = 0.000$, $z = -6.949$.; §Analyzed by Mann–Whitney *U*-test, 3 months at postoperative compared with preoperative, $p = 0.000$, $z = -6.771$.; **Analyzed by Mann–Whitney *U*-test, 3 months at postoperative compared with preoperative, $p = 0.000$, $z = -6.765$.

TABLE 4 Radiographic details and outcomes of the 31 patients

Parameters	$N = 31$
Flexibility on x-ray (%)	17.5 ± 7.8
Flexibility on MRI (%)	43.6 ± 11*
Cervical kyphosis angle (°)	
Preoperative	46.1 ± 7.7
After traction	13.2 ± 3.2†
Postoperative	−6.1 ± 4.3‡
Final follow-up	−5.4 ± 3.9§
Corrective rate after traction (%)	71.3 ± 4.7
Corrective rate after at final follow-up (%)	113.1 ± 10.3
Loss of correction at final follow-up (°)	0.7 ± 1.1

*Analyzed by paired Student's *t*-test, MRI-flexibility compared with X-flexibility, $p = 0.000$, $t = -10.309$.; †Analyzed by paired Student's *t*-test, after traction compared with preoperative, $p = 0.000$, $t = 32.420$.; ‡Analyzed by paired Student's *t*-test, postoperative compared with preoperative, $p = 0.000$, $t = 51.673$.; §Analyzed by paired Student's *t*-test, final follow-up compared with preoperative, $p = 0.000$, $t = 51.602$.

with anterior debridement, autologous iliac bone grafting, and internal plate fixation can be an effective and safe surgical method for the treatment of CTB with severe kyphosis. Through 2 years of follow-up, the neurological deficits recovered significantly, and the VAS neck pain and JOA scores also obtained significant improvement at the final follow-up. The cervical kyphosis was corrected and well maintained, all patients achieved solid bone fusion, and no recurrence was observed.

The Feasibility of Preoperative Skull Traction

Cervical kyphosis can be categorized as flexible or fixed deformities, which is of great significance for the surgical decision-making process. Fixed kyphosis is usually characterized by postural rigidity accompanied by ankylosis of one or more cervical segments, which can be evaluated on CT scans. In this condition, preoperative skull traction might have little to no significant value, and anterior surgery hardly achieves satisfactory correction, so combined anterior and posterior surgery is often recommended.[20–22] For flexible kyphosis, no segmental ankylosis exists on CT scan, and a significant reduction of the kyphosis could be observed on cervical extension X-ray. In this condition, some surgeons recommended isolated anterior surgery or combined preoperative skull traction for patients with severe kyphosis.[11,13,14] Meanwhile, for these patients, their preoperative flexibility of cervical kyphosis can be used to estimate the corrective effect that might be obtained through skull traction: the greater the flexibility is, the better the potential corrective rate. The traditional method of evaluating flexibility is based on dynamic extension-flexion X-rays, and kyphosis can be considered flexible when its flexibility is greater than 30%–50%. In this study, the mean kyphosis Cobb angle on the extension X-rays was 37.9° ± 6.7°, and the mean flexibility was relatively small (17.5% ± 7.8%), which indicated that it might be difficult to obtain a good reduction through preoperative skull traction. Of note, patients enrolled in this study all suffered neck pain (31/31, 100%). When patients undergo dynamic extension-flexion X-rays, neck pain might inevitably lead to local muscle stiffness and further limit the ability to perform extremes of extension and flexion, which might result in lower flexibility than in the actual situation. Therefore, we believe that local muscle relaxation is essential for the assessment of real flexibility, and cervical MRI might be a perfect alternative. The main reasons are as follows: on the one hand, the MRI image obtained in the supine position allows the weight of the body to create a lordotic force that uses the apex of the kyphosis as a fulcrum and then acts on the whole neck to gradually reduce the cervical kyphosis; on the other hand, a considerable amount of time (approximately 30 min) is required to complete the MRI, and a prolonged time in the supine position at a resting state might gradually relieve neck pain and completely relax local muscles, providing a greater ability for reduction of the kyphosis. Thus, the mean kyphosis Cobb angle on MRI was 25.9° ± 6.7°, which was significantly smaller than that on

extension X-ray ($p = 0.000$). The mean flexibility calculated by comparing supine MRI versus standing neutral lateral X-ray was 43.6% ± 11.0%. Therefore, we still performed skull traction for all patients even when traditional extension-flexion X-rays showed relatively low flexibility. All the patients finally obtained a satisfactory correction with a mean corrective rate of 71.3% ± 4.7% through skull traction, which partly confirmed the feasibility of MRI for assessing the flexibility of patients with cervical kyphosis. Considering that cervical MRI is an essential routine examination (assessing local compression to the spinal cord and nerve root) for patients with CTBK, choosing supine MRI instead of extension-flexion X-rays for flexibility assessment is of great significance in reducing additional radiation and medical costs.

The Safety and Efficacy of Skull Traction Combined with an Anterior Surgery

Isolated anterior surgery has become the most common surgical approach for patients with CTB, enabling direct exposure of the lesions throughout debridement.[11–14,18] Wu et al.[11] conducted a retrospective study of 17 patients with CTB and found that anterior surgery could achieve complete debridement, spinal cord decompression, and satisfactory kyphosis correction and was well maintained. However, the kyphosis of patients enrolled in their study was slight (Cobb angle range −7 to 27.3). In the discussion, the authors also noted that their study was relatively insufficient to guide patients with kyphosis Cobb angles of more than 30°, and the surgical approach for patients with significant kyphosis needed further study. By reviewing the related literature, we found that some studies included some patients with severe kyphosis. Hassan[18] reported that 16 patients with CTB obtained satisfactory outcomes through anterior surgery, in which preoperative skull traction was performed in seven patients whose kyphotic angles were more than 20°. Mao et al.[13] proved the efficacy of one-stage anterior surgery by performing a retrospective study of 21 patients with more than 5 years of follow-up, where external traction was used preoperatively to improve correction in seven patients who had kyphosis angles of more than 35°. In addition, Djoubairou et al.[23] presented a case report of a C4-5 tuberculosis patient with severe angulation who finally achieved satisfactory results through preoperative skull traction combined with anterior debridement, tricortical bone grafting, and internal plate fixation. Although the sample size was small in these previous studies, they all suggested that preoperative skull traction might be an indispensable procedure for the treatment of CTB patients with severe kyphosis. In this study, we first proved the safety, feasibility, and efficacy of skull traction combined with anterior surgery for the treatment of cervical tuberculosis with significant kyphosis (>35°) in the largest case series to date. Although the patients had severe kyphosis with a relatively high risk of spinal cord injury during corrective surgery, no neurological deterioration occurred following the operation. This might be because surgical treatment for tuberculous kyphosis after skull traction is relatively safe and is more conducive to anterior debridement and decompression. Due to tolerance to gradual traction preoperatively, spinal cord injury caused by overcorrection does not easily occur.

Considering the growth potential of posterior elements, isolated anterior surgery might cause disproportionate growth potential between fused anterior elements and unfused posterior elements in the long term. Therefore, some surgeons believe that posterior fixation plays an irreplaceable role in the correction and maintenance of kyphosis for the treatment of CTB, and the combined anterior–posterior approach should be recommended as a priority.[16,17] In our study, all the patients achieved a satisfactory correction with a mean corrective rate of 113.1% ± 10.3% by the final follow-up. During the 2-year follow-up, the average correction loss was only 0.7° ± 1.1°, and there was no significant difference between the kyphotic angle postoperatively and at the final follow-up (−6.1 ± 4.3° vs. −5.4 ± 3.9°, $p = 0.500$). The reason for this good outcome might be that the patients enrolled in this study were all adults (age range 22–57 years) with limited or no spinal growth potential, which hardly caused an imbalance in growth between the anterior and posterior elements during the follow-up. Therefore, we believe that the age of the patient is also crucial in the surgical plan decision.

Surgery Tips for the Correction of Cervical Kyphosis

Preoperative skull traction can be used as an initial tool in the evaluation of the surgical approach to treat cervical tuberculosis with significant kyphosis. When kyphosis is significantly reduced after traction, isolated anterior surgery can be performed. Meanwhile, it can relieve spinal cord compression, improve kyphosis, and provide better conditions for anterior corrective surgery. During the anterior procedure, a few concepts should be kept in mind to optimize the correction: (1) Patient positioning is important in preparing for the anterior correction of kyphosis. The neck was placed initially in slight extension, and after decompression, the donut was removed to further extend the cervical spine. (2) Distraction posts were placed in a convergent fashion to obtain cervical extension and further lordosis. (3) Optimally, decompression was performed via multiple discectomies or via discectomy combined with corpectomy. Multiple sequential corpectomies should be prevented to provide intervening vertebral bodies for multiple points of fixation and prevent potential internal fixation failure. (4) The anterior plate may be shaped in slight lordosis to make the correction easier. As the screws are tightened, the spine is "brought to the implant," which is conducive to correcting the deformity and maintaining lordosis.

Strengths and Limitations

This study first proved the safety, feasibility, and efficacy of preoperative skull traction combined with anterior surgery for the treatment of cervical tuberculosis with significant kyphosis in the largest case series to date. We provided an alternative method, supine-MRI versus standing lateral X-ray, to evaluate the flexibility of cervical kyphosis, which might be an alternative to the traditional method based on

dynamic extension-flexion X-rays. However, there were several limitations in this study. First, it was a retrospective study based on a single-center database, which may bias the results. Second, the follow-up was relatively short, and long-term follow-up is needed for further study.

Conclusion

Preoperatively, skull traction combined with anterior debridement, autologous iliac bone grafting, and internal plate fixation can be an effective and safe surgical method for the treatment of cervical tuberculosis with severe kyphosis. It can completely clear the tuberculosis lesion, achieve full decompression, effectively correct kyphosis, avoid loss of correction, and reconstruct the local stability. Since the spinal cord can adapt to slow stretching, preoperative skull traction can not only improve kyphosis but also provide better conditions for surgical treatment. With tolerance to gradual traction, spinal cord injury caused by overcorrection does not easily occur during corrective surgery.

AUTHOR CONTRIBUTIONS

All authors had full access to the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Zhuang Zhang, Yue-ming Song, and Xi Yang. Acquisition of data: Zhuang Zhang, Ce Zhu, Li-min Liu, and Tao Li. Analysis and interpretation of the data: Zhuang Zhang and Ce Zhu. Drafting of the manuscript: Zhuang Zhang, Ce Zhu, and Li-min Liu. Critical revision of the manuscript for important intellectual content: Tao Li, Yue-ming Song, and Xi Yang. Statistical analysis: Zhuang Zhang and Ce Zhu. Obtained funding: Yue-ming Song. Study supervision: Yue-ming Song and Xi Yang.

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CONFLICT OF INTEREST STATEMENT

The authors have no relevant conflicts of interests to disclose.

ETHICS STATEMENT

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the West China hospital (No. 2021–271). Written informed consent was obtained from the patients.

References

1. Shetty AP, Viswanathan VK, Rajasekaran S. Cervical spine TB-current concepts in management. J Orthop Surg (Hong Kong). 2021;29(1_suppl): 23094990211006936.
2. Pourbaix A, Zarrouk V, Allaham W, Leflon V, Rousseau MA, Goutagny S, et al. More complications in cervical than in non-cervical spine tuberculosis. Infect Dis (Lond). 2020;52(3):170–6.
3. Yao M, Zhu ZH, Lian NF, Hu YQ, Ding Y, Zhou J, et al. Treatment for 15 cases of cervical tuberculosis. Chin Med J (Engl). 2017;130(14):1751–2.
4. Wang XY, Luo CK, Li WW, Wu P, Pang XY, Xu ZQ, et al. A practical therapeutic protocol for cervical tuberculosis. Eur J Trauma Emerg Surg. 2013;39(1):93–9.
5. Ogura Y, Dimar JR, Djurasovic M, Carreon LY. Etiology and treatment of cervical kyphosis: state of the art review-a narrative review. J Spine Surg. 2021; 7(3):422–33.
6. Scheer JK, Tang JA, Smith JS, Acosta FL, Protopsaltis TS, Blondel B, et al. Cervical spine alignment, sagittal deformity, and clinical implications: a review. J Neurosurg Spine. 2013;19(2):141–59.
7. Yuan B, Zhao Y, Zhou S, Wang Z, Chen X, Jia L. Treatment for tuberculosis of the subaxial cervical spine: a systematic review. Arch Orthop Trauma Surg. 2021; 141(11):1863–76.
8. Tang VK, Hsu HL, Hsieh TC, Lee WS. Vertebral tuberculosis complicated with retropharyngeal, parathoracic, and huge iliopsoas abscess, successfully treated with image-guided percutaneous drainage. J Microbiol Immunol Infect. 2017; 50(2):263–4.
9. Kim CW, Hyun SJ, Kim KJ. Surgical impact on global sagittal alignment and health-related quality of life following cervical kyphosis correction surgery: systematic review. Neurospine. 2020;17(3):497–504.
10. Patwardhan AG, Khayatzadeh S, Havey RM, Voronov LI, Smith ZA, Kalmanson O, et al. Cervical sagittal balance: a biomechanical perspective can help clinical practice. Eur Spine J. 2018;27(Suppl 1):25–38.
11. Wu W, Li Z, Lin R, Zhang H, Lin J. Anterior debridement, decompression, fusion and instrumentation for lower cervical spine tuberculosis. J Orthop Sci. 2020;25(3):400–4.
12. Luan H, Liu K, Wang Y, Kahaer A, Sheng W, Maimaiti M, et al. Efficacy of anterior debridement and bone grafting with fusion using internal fixation combined with anti-tuberculosis chemotherapy in the treatment of subaxial cervical tuberculosis. BMC Surg. 2022;22(1):150.
13. Mao N, Shi Z, Ni H, Zhao Y, Tang H, Liu D, et al. Long-term outcomes of one-stage anterior debridement, bone grafting, and internal fixation for the treatment of lower cervical tuberculosis with kyphosis. Br J Neurosurg. 2013; 27(2):160–6.
14. He M, Xu H, Zhao J, Wang Z. Anterior debridement, decompression, bone grafting, and instrumentation for lower cervical spine tuberculosis. Spine J. 2014; 14(4):619–27.
15. Hsu LC, Leong JC. Tuberculosis of the lower cervical spine (C2 to C7). A report on 40 cases. J Bone Joint Surg Br. 1984;66(1):1–5.
16. Zeng H, Liang Y, Wang X, Shen X, Luo C, Xu Z, et al. Halo traction, single-segment circumferential fixation treating cervical tubercular spondylitis with kyphosis. Clin Neurol Neurosurg. 2015;138:59–65.
17. Zeng H, Shen X, Luo C, Xu Z, Zhang Y, Liu Z, et al. 360-degree cervical spinal arthrodesis for treatment of pediatric cervical spinal tuberculosis with kyphosis. BMC Musculoskelet Disord. 2016;17:175.
18. Hassan MG. Anterior plating for lower cervical spine tuberculosis. Int Orthop. 2003;27(2):73–7.
19. Brantigan JW, Steffee AD. A carbon fiber implant to aid interbody lumbar fusion. Two-year clinical results in the first 26 patients. Spine (Phila Pa 1976). 1993;18(14):2106–7.
20. Garg B, Mehta N, Vatsya P. Surgical strategy for correction of severe, rigid, post-tubercular cervical kyphosis: an experience of two cases. Spine Deform. 2020;8(4):801–7.
21. Kasliwal MK. Single Stage 360 degrees correction of fixed cervical deformity with anterior and posterior ankyloses. Asian J Neurosurg. 2019;14(2):612–3.
22. Koller H, Ames C, Mehdian H, Bartels R, Ferch R, Deriven V, et al. Characteristics of deformity surgery in patients with severe and rigid cervical kyphosis (CK): results of the CSRS-Europe multi-Centre study project. Eur Spine J. 2019;28(2):324–44.
23. Djoubairou BO, El Fatemi N, Karekezi C, Gana R, Maaqili MR, El Abbadi N. Tuberculosis of lower cervical spine (C4-C5) with severe angulation. Spine J. 2015;15(10):e25–6.