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Short-term clinical outcomes and technical advantages of mini-open endoscope assisted anterior cervical discectomy and fusion in the treatment of cervical spondylotic myelopathy

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Abstract

Background Although anterior cervical discectomy and fusion (ACDF) is the gold standard for treating cervical spondylotic myelopathy (CSM), it still has several disadvantages in spite the used of microscope. Unilateral biportal endoscopy is a newly developed minimally invasive spine surgery and has many advantages. The study aimed to compare the feasibility, technical advantages and short-term clinical efficacy of mini-open endoscope assisted ACDF (MOEA-ACDF) *versus* microscopic ACDF and traditional ACDF for the treatment of single-level CSM accompanied by osteophyte formation at the posterior edge of the vertebral body or ossification of posterior longitudinal ligament.

Methods Thirty-three patients who treated with MOEA-ACDF (Group A), microscopic ACDF (Group B) and traditional ACDF (Group C) were included. Before surgery, at 1 month after surgery and the last follow-up, imaging indicators (cervical Cobb angle, Cobb angle of fused segment, intervertebral space height of fused segment, intervertebral fusion status), and clinical indicators, including visual analogue scale (VAS) scores for neck and upper extremity pain, Japanese orthopedic association (JOA) score, and neck disability index (NDI) were analyzed.

Results The operations were successfully completed in all groups. The mean follow-up time was 20.5 ± 2.8, 20.2 ± 4.3, and 20.3 ± 3.7 months in Groups A, B, C, respectively. Group A had longer operation time and shorter length of skin incision than Groups B and C (all $P < 0.05$). All patients in each group had achieved bony fusion during the follow-up period, no significant difference in the time taken for bony fusion was noted between the three groups. Imaging and clinical indicators both improved significantly at 1 month after surgery and the last follow-up compared with before surgery in all groups (all $P < 0.05$). There was no significant difference in imaging and clinical indicators, JOA recovery rate, and the complication rates among the three group after surgery.

Conclusions For the treatment of CSM accompanied by osteophyte formation at the posterior edge of the vertebral body or OPLL, MOEA-ACDF can achieve satisfactory short-term clinical outcomes, with the advantages of high

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overall surgical safety, good operation accuracy, less cervical soft tissue damage, low complication rate, and fast postoperative recovery.

Keywords Mini-open endoscope assisted anterior cervical discectomy and fusion, Single-level cervical spondylotic myelopathy, Decompression, Zero-profile, Clinical outcomes

Background

Cervical spondylotic myelopathy (CSM) is a serious type of degenerative cervical myelopathy. It poses the greatest threat to human health and accounts for 10–15% of all cervical spondylosis types. For patients who have a definite diagnosis of CSM, surgical treatment should be adopted if there are no surgical contraindications to save the damaged spinal cord nerve function and strive for the greatest possibility of recovery. Furthermore, surgical treatment should focus on adequate decompression of the spinal cord nerves, reconstruction of the cervical physiological curve, and intervertebral height, while emphasizing the reconstruction of cervical stability and physiological balance [1–3]. An anterior cervical discectomy and fusion (ACDF) can relieve the compression to spinal cord by removal of compressive factors at the anterior spinal cord, thus achieving the purpose of spinal nerve decompression and reconstruction of the stability and physiological balance of the cervical spine with the assistance of devices such as titanium plates and fusion cages. ACDF has highly accurate clinical efficacy, with a high rate of bone graft fusion, and is known as the "gold standard" for the treatment of cervical degenerative diseases [4–6].

With the rapid development of the economy and technology in the new era, medical technology continues to innovate, and the concept of minimally invasive surgery and enhanced recovery continues to be deeply rooted in people's hearts. Traditional ACDF technology has been gradually improved. The application of minimally invasive spinal surgery has emerged, and various minimally invasive techniques are being continuously applied in clinical practice. In 1975, Hankinson et al. [7] first applied microscope technology to anterior cervical decompression, the use of a high-powered microscope allowed for a clearer and more detailed view of the surgical site, thus improving the accuracy of the decompression procedure, reducing bleeding, and resulting in satisfactory clinical outcomes. Vergara et al. [8] achieved success in performing microscopic ACDF using a channel system in six cases, and reported that microscopic ACDF could be a promising alternative to traditional open surgery. Microscopic ACDF has become a standard surgical procedure worldwide in neurosurgery and spinal surgery. Nevertheless, some surgeons have still reported maneuverability difficulties and operative field encumbrance as reasons for the limited use of microscopic ACDF in spinal procedures, especially when implants with dedicated surgical instruments (which can be too long to be used under the microscope) are required [9, 10]. Microscopic surgery often necessitates the use of aspirators to remove blood or bone debris from the operative field to maintain clear visualization, which can prolong the surgical time and increase the risk of spinal cord nerve injury.

Another iconic technique in minimally invasive spinal surgery is spinal endoscopy, and many scholars have been persistently exploring how to use spinal endoscopy safely and efficiently in ACDF. Tan et al. [11] reported the use of endoscopic ACDF in the treatment of 16 patients with cervical spondylosis, and considered that endoscopic ACDF has the advantages of small incision, mild tissue damage, and safe surgical operation, all of which make it particularly suitable for handling segments C4-5 and C5-6. Yao et al. [12] conducted a followed up for more than 5 years in which they successfully treated 67 patients with cervical disc herniation using endoscopic ACDF. During the surgery, important organs such as the esophagus, trachea, and blood vessels were effectively shielded outside the surgical area through a 2 cm-diameter working channel. After surgery, all surgical segments achieved complete fusion, and observation indicators such as JOA score, VAS score and height of the anterior edge of the intervertebral space were substantially improved.

Although endoscopic techniques have been tried in anterior cervical surgery from time to time, their widespread application in the cervical spine is still limited compared with their use in lumbar spine surgery. Firstly, reports on cervical endoscopic techniques are often found in the treatment of cervical spondylotic radiculopathy, while there are relatively few literature reports on the use of cervical endoscopic techniques in the study of CSM [11–14]. Secondly, there is a risk of remarkable organ damage and irrigation fluid retention through the anterior cervical approach. Currently, the clinical applications of cervical endoscopic techniques mainly focus on posterior cervical surgery, such as percutaneous endoscopic cervical foraminotomy, percutaneous endoscopic cervical single- or double-door laminoplasty, and percutaneous endoscopic cervical keyhole surgeries [14–17]. Thirdly, although anterior percutaneous endoscopic cervical discectomy (APECD) is currently the most reported anterior cervical endoscopic technique, it is mainly suitable for cervical spondylotic radiculopathy or CSM caused by soft intervertebral disc herniation. However, it is not suitable for CSM accompanied by osteophyte formation at the posterior border of the

vertebral body or ossification of the posterior longitudinal ligament (OPLL). Since APECD is a non-fusion surgery, it cannot be used to reconstruct the mechanical stability of the cervical spine [18–19]. Fourthly, Tan et al. and Yao et al. [11–12] performed endoscopic ACDF with rigid channels to create a safe working space for endoscopic operations, but this also limited the use of operating instruments, especially during surgery where it was difficult to install interbody distractor. The endoscopic lens should be pulled by surgeons or anesthesiologists to widen the intervertebral space, which not only consumed human resources but also made it difficult to ensure the pulling effect. Lastly, previous studies on endoscopic ACDF have lacked case control studies that compare endoscopic ACDF with microscopic ACDF or traditional ACDF [11–12, 20].

Unilateral biportal endoscopy (UBE) is a novel minimally invasive spine surgery that has been gradually gaining popularity in the minimally invasive spinal surgery field in recent years. It was first proposed by De Antoni et al. in 1996 [21], and further named by Heo et al. in 2017 [22]. The UBE technique is not limited by rigid working channels. The viewing portal and the working portal are separated, the endoscope and instruments can form a floating triangular relationship. The lens has a small diameter and a wide field of view, allowing it to extend into narrow spaces and explore the areas that cannot be observed by the naked eyes or microscope. The circulating water medium enhances the clarity and wideness of the endoscopic field of view, making the processing of fine structures more precise and efficient. In addition, conventional open surgical instruments can be used, making the operation more flexible and convenient, truly reflecting the operational concept of endoscopic surgery [23–26].

Considering the shortcomings of previous clinical applications of anterior cervical endoscopic techniques and the great success of UBE technique in lumbar, thoracic, and posterior cervical surgeries, we have modified the UBE technique and concepts based on actual clinical practice to assist ACDF for the treatment of CSM since May 2020, and named it "mini-open endoscope assisted ACDF (MOEA-ACDF)". In this study, we retrospective analyzed the data of patients with CSM who underwent MOEA-ACDF, microscopic ACDF, and traditional ACDF, and aimed to (1) explore the feasibility of MOEA-ACDF in the treatment of CSM; (2) compare the potential technical advantages and short-term clinical efficacy of MOEA-ACDF versus microscopic ACDF and traditional ACDF in the treatment of CSM; (3) summarize the operational key points and precautions for applying endoscopic techniques in ACDF.

Materials and methods

Subjects

This is a retrospective case-control study. A total of 15 patients with single-level CSM who were treated with MOEA-ACDF in our department from May 2020 to December 2021 were retrospectively reviewed.

The inclusion criteria included: (1) patients who had a definite diagnosis of CSM, with the compression material being located on the ventral side of the spinal cord, and a single segment being affected; (2) imaging data showed narrowing of the diseased intervertebral space, with osteophyte formation at the posterior edge of the vertebral body or OPLL to varying degrees; (3) patients who underwent MOEA-ACDF, and received reconstruction of the cervical spine using a zero-profile device (Zero-p) following decompression, and all of them received 2 courses of electroacupuncture after operation; (4) patients who received microscopic ACDF or traditional ACDF during the same period were included as controls; (5) patients who had complete follow-up data.

Exclusion criteria included: (1) patients who were diagnosed with cervical spondylotic radiculopathy or other types of cervical spondylosis; (2) more than 2 segments were affected; (3) patients who were treated with other surgeries or fixation and fusion methods; (4) patients who had a history of previous cervical spine surgery, trauma, as well as infection, tumor, severe osteoporosis, metabolic diseases, and allergies to implanted materials; (5) patients who cannot tolerate surgery due to the presence of severe systematic diseases; (6) patients who had incomplete follow-up imaging data.

According to the inclusion and exclusion criteria detailed above, 11 patients who underwent MOEA-ACDF were included in this study, and defined as Group A. There were 5 males and 6 females, with a mean age of 50.7 ± 11.2 years (range 35–71 years), a body mass index (BMI) of 24.4 ± 3.0 kg/m^2 (range 19.4–30.5 kg/m^2). The operative segment was C3-4 in 1 patient, C4-5 in 2 patients, C5-6 in 6 patients, and C6-7 in 2 patients.

Eleven patients with single-level CSM who received microscopic ACDF and 11 patients with single-level CSM who received traditional ACDF in our hospital during the same period were included, and defined as Groups B, C.The inclusion and exclusion criteria were the same as those of group A except for surgical methods. There were 5 males and 6 females in the two groups, respectively. The age of group B was 50.6 ± 9.8 years, and the age of group C was 50.6 ± 9.8 years. The BMI of group B was 24.4 ± 3.0 kg/m2, and the BMI of group C was 24.4 ± 2.9 kg/m2.Both the three groups were matched for sex, age, BMI, and operative segments.

All patients had symptoms of cervical spinal cord compression, including pain and discomfort in the neck and shoulder, numbness in one or both upper limbs, loss of

dexterity in one or both hands, these symptoms were aggravated by movements. Instability in walking was observed in 5 (45.5%) patients in Group A, 4 (36.4%) patients in Group B, and 5 (45.5%) patients in Group C, the main manifestations were unsteady walking and a feeling of walking on cotton. Unilateral or bilateral muscular atrophy of the hands was found in 3 (27.3%) patients in Group A, 3 (27.3%) patients in Group B, and 4 (36.4%) patients in Group C, the main manifestations were varying degrees of decreased handgrip strength and difficulty with holding objects.

All patients underwent routine anteroposterior (AP), lateral, hyperflexion, and hyperextension X-rays, CT and MRI of the cervical spine before surgery. AP and lateral X-rays of the cervical spine showed reduced intervertebral space height of the responsible segment in all patients. Hyperflexion and hyperextension X-rays showed segmental instability, including the presence of angulation deformity of the intervertebral space, displacement and slippage in 4 (36.4%) patients in Group A, 3 (27.3%) patients in Group B, and 4 (36.4%) patients in Group C. CT documented intervertebral disc herniation at the responsible segment, with varying degrees of osteophyte formation at the anterior and posterior edges of the vertebral body in all patients, and OPLL was observed in 5 (45.5%) patients in each group. MRI revealed different degrees of intervertebral disc herniation at the responsible segment, and anterior spinal cord compression in all patients, spinal cord degeneration was observed in 7 (63.6%) patients in Group A, 7 (63.6%) patients in Group B, and 8 (72.7%) patients in Group C.

This study was performed in line with the principles of the Declaration of Helsinki, and was approved by the Ethics Committee of the Second Affiliated Hospital of Anhui Medical University (sl-xjs2019-001). Written informed consent was obtained from all patients and their families.

Instruments

The arthroscopy system includes a monitor, a light source system, a 30-degree arthroscope, a 0-degree arthroscope, radio-frequency plasma surgical electrodes (Beijing Jeswis Technology Co., Ltd., Beijing, China), and a high-speed power grinding drill (Guizhou Zirui Technology, Guizhou, China). The microscope (Zeiss TIVATO 700) was provided by Carl Zeiss (Shanghai, China). Surgical instruments used for traditional anterior cervical spine surgery include bipolar electrocoagulation hemostatic forceps, high-frequency electric knife, periosteal elevator, nerve probe, laminar rongeur, nucleus pulposus forcep, long-handled spatula, Caspar distractor, S-shaped hook, and 2.0-mm-diameter Kirschner wire (K-wire). The instruments used for the reconstruction of the cervical spine include Zero-p, DePuy Synthes, MA, USA), and bone allografts (Biomaterial Co., Ltd., Hubei, China).

Surgical procedures

MOEA-ACDF procedures

Anesthesia and patient positioning

All patients underwent general anesthesia with endotracheal intubation. Invasive circulation monitoring and anaesthetic depth monitoring were recommended for patients of advanced age or those with high American Society of Anesthesiologists classifications. During surgery, controlled hypotension and maintenance of satisfactory muscular relaxation were considered. Patients were placed in the supine position with pillows placed underneath their shoulder, back and the neck. A silicone head ring was placed under patients' head followed by slight posterior extension of their head. The position of head was checked to ensure that it was stable. Arms were pulled distally, and stabilized on either side of the body.

Incision planning and surgical area preparation

Under C-arm guidance using a K-wire, an incision was precisely positioned on the skin corresponding to the intervertebral space scheduled for decompression. A transverse skin incision was made approximately 2 cm in length on the anterior region of the neck on the right side. The incision length can be adjusted appropriately according to the status of different patients. The surgical area was routinely disinfected, and covered with sterile towel. The incision was covered with a protective adhesive film equipped with a drainage device for fluid irrigation.

Approach and exposure of the operative space

The operator stood on the right side of the patient. With the use of Smith-Peterson approach, the skin and platysma were cut successively according to the incision marking. A vascular forcep was used to distract the sternocleidomastoid muscle, medial cervical vascular sheath, the space lateral to trachea and esophagus, the cervical vascular sheath was touched with the index finger for protection. A vascular forceps or periosteal elevator was used to bluntly dissect the loose connective tissues layer by layer to expose the prevertebral fascia. C-arm x-ray machine was used to identify the responsible intervertebral space. The prevertebral fascia (2–3 mm above and below the responsible intervertebral space) was dissected using a high-frequency electric knife to expose the anterior intervertebral disc space, part of the edge of the vertebral body, and bilateral Luschka joints. A long-handled sharp knife was used to dissect the annulus fibrosus close to the adjacent endplate until the bilateral Luschka joints were reached, and the nucleus pulposus was removed with a nucleus pulposus forceps. A Caspar distractor was placed on the medial aspect of the Luschka joint at the adjacent vertebral body on the left side close to the bony endplates in order to distract the diseased intervertebral space. 2.0-mm-diameter K-wires were inserted

into the corresponding site on the right side of the upper and lower vertebral bodies. And an S-shaped hook was placed between the Casper distractor and the esophagus to achieve self-stabilization with the support of the elasticity of the soft tissues, thus forming a surgical area of approximately 2 cm in diameter. Assistance from assistants was not needed when performing operations in this area, that can effectively avoid soft tissues, such as the esophagus, from entering the operation path during surgery (Fig. 1).

Endoscopic discectomy and spinal cord decompression

The sheath and inner core were inserted into the surgical area. Then an arthroscope was inserted after pulling out the inner core. After a gravity-perfusate system was connected, 3 L isotonic saline was used as flushing fluid, and placed at a level of approximately 50–60 cm above the surface of the surgical incision. Irrigation with normal saline was performed until a clear endoscopic visual field was obtained. The operator held the arthroscope in his left hand and the instrument in his right hand (Fig. 2). Under visual field of the arthroscopy with a 30-degree or a 0-degree arthroscope, a laminar rongeur was used to remove the lip-like hyperplasia at the inferior edge of upper vertebral body in order to widen the portal to the intervertebral space, and a long-handled spatula was used to clear the remaining intervertebral disc tissues and cartilage endplate until the posterior edge of the vertebral body was reached (Fig. 3A, B).The ventral or dorsal side of the posterior longitudinal ligament (PLL) is examined for prolapse or free nucleus pulposus. If so, the nucleus pulposus can be pulled out. The starting point for bone grinding with a drill was determined according to the length of the fusion device to ensure a complete match between the fusion device and the remaining bony endplate. According to the width of the base of osteophytes at the posterior edge of the vertebral body revealed by the preoperative imaging images, the cortex of the base

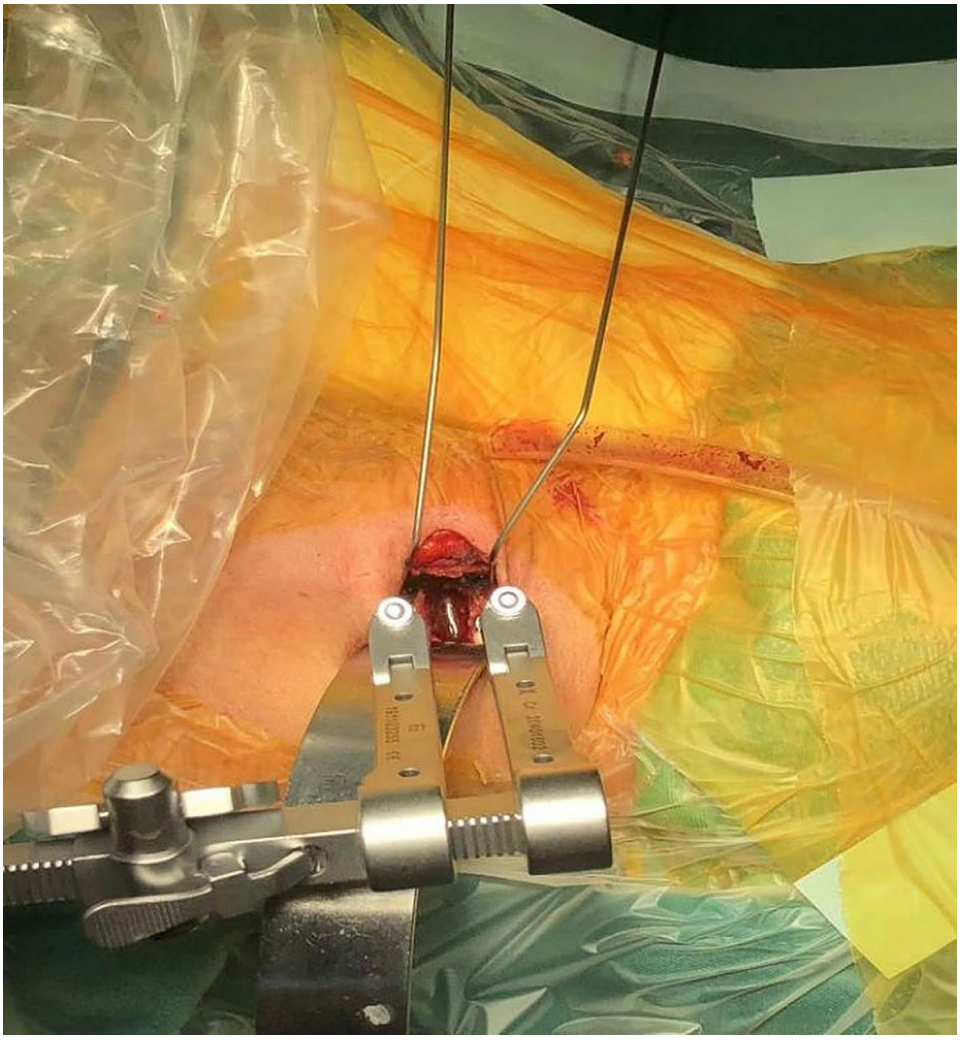

Fig. 1 Surgical area preparation and maintenance of the operative space

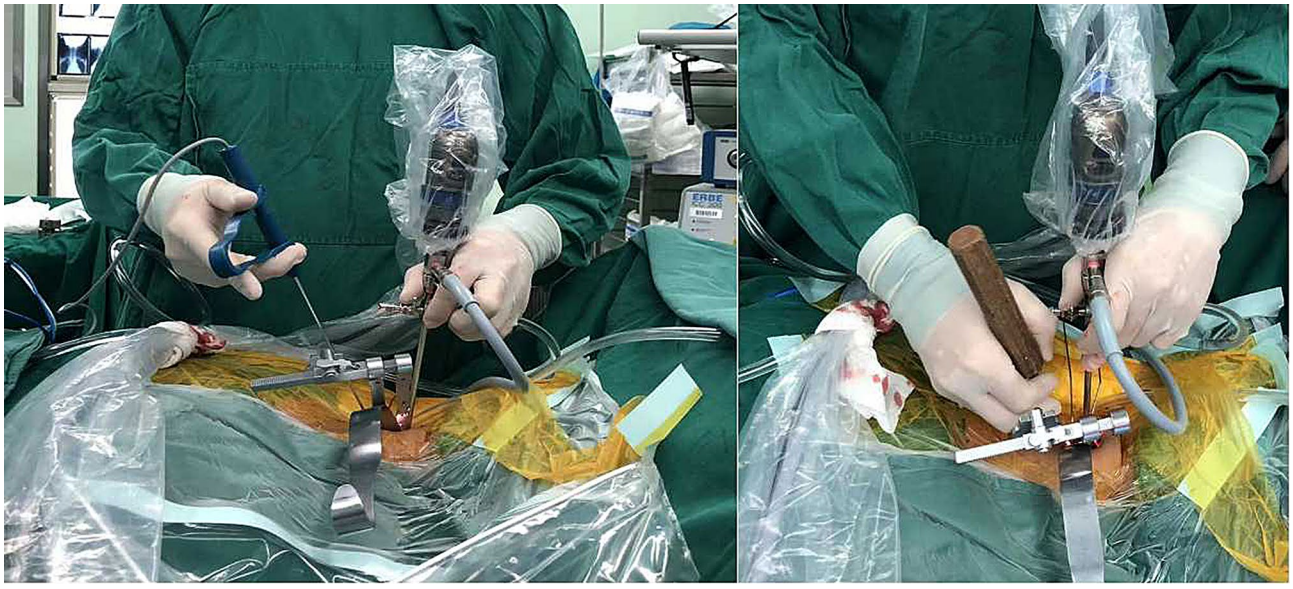

Fig. 2 The operator held the arthroscope in his left hand and the instrument in his right hand

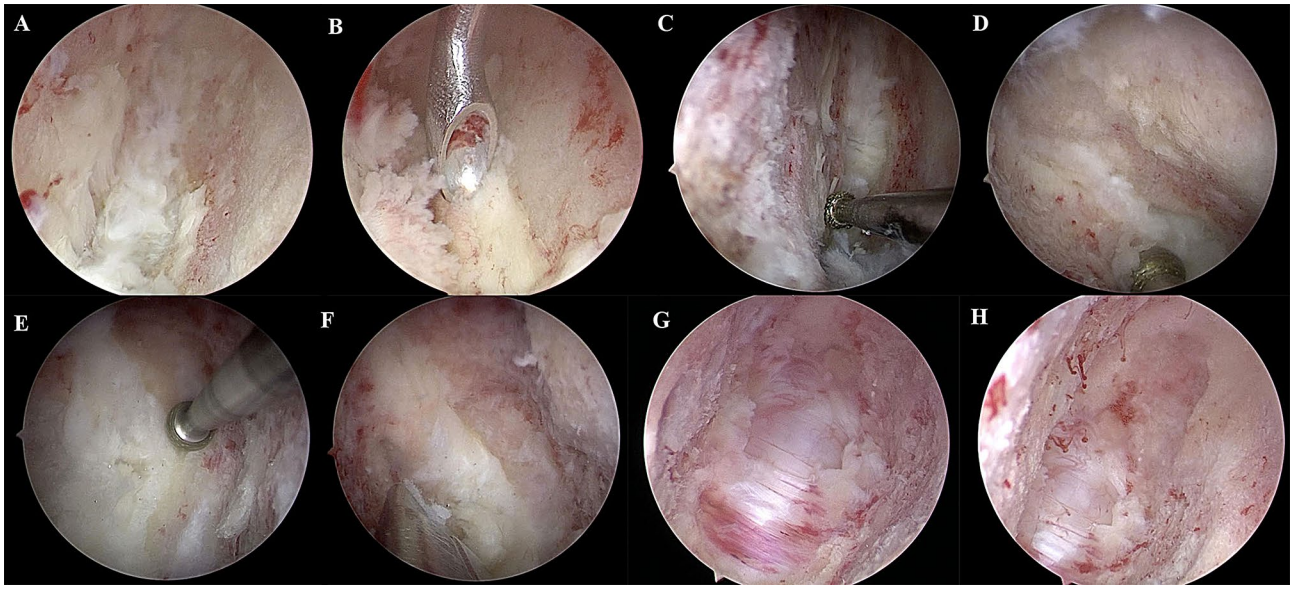

Fig. 3 MOEA-ACDF procedures performed under endoscopic view. **A**: Widening of the portal to the intervertebral space until the posterior edges of the vertebral body was reached. **B**: Removal of remaining intervertebral disc tissues using a long-handled spatula. **C**: Determination of the starting point for bone grinding with a drill. **D**: The use of bone wax to stop bony bleeding by sticking to the grinding drill. **E**: Grinding the cortex bone of the base of the osteophyte with a high-speed grinding drill. **F**: Removal of the osteophytes at the posterior edge of the vertebral body using a fine-tipped laminar rongeur. **G**: Clearly distinguishing between the posterior longitudinal ligament and the dural sac under endoscopic view. **H**: Visible punctate bleeding from the bony endplates seen after the fluid irrigation was temporally clamped

of the osteophytes was thinned using a high-speed grinding drill in a trumpet-like-shaped manner (Figs. 3C-E). Drill the bone cortex until it is thin and soft, and a nerve probe identifies the space between the bone cortex and the PLL. A 1-mm laminar rongeur was used to remove the osteophytes at the posterior edge of the vertebral body. If removal of the osteophytes were difficult due to their large size, a long-handled spatula can be used to remove the osteophytes by fracturing them ventrally far away from the spinal cord (Fig. 3F). The Luschka joints with hypertrophic changes on both sides were removed along the posterior edge of the vertebral body with a spatula or a high-speed grinding drill. Bleeding was stopped carefully using bone wax or radio-frequency plasma surgical electrode to ensure a clear endoscopic view of all anatomic structures. For isolated ossified PLL

behind the intervertebral space, a portion of bone at the posterior edge of the vertebral body was removed using a high-speed grinding drill, a spatula, or a laminar rongeur to expose the anterior and posterior edges of the isolated ossified PLL. A nerve probe was used to identify the weak point of the PLL, which was then lifted by an assistant and cut by the operator using a sharp knife. The PLL can also be incised directly far away from the spinal cord by the operator using a specialized anterior cervical hook knife. The ossified PLL was then removed to expose the dural sac (Fig. 3G). Finally, the nerve probe was used to confirm adequate decompression and the absence of residual compressive materials. And under visual field of the arthroscopy with a 30-degree arthroscope, the completion of sneak decompression of each part was detected.

Placement of fusion cage and suture closure of incision

The lens of the 30-degree endoscope was turned to observe the fusion interface between the head end and tail end. A long-handled spatula was used to remove the residual nucleus pulposus, the upper and lower cartilage endplates until punctate bleeding from the bony endplates were seen, care must be taken to avoid damaging the bony endplates (Fig. 3H). The arthroscopic system was slowly withdrawn, the presence and absence of active bleeding in the surgical field was checked, and bleeding should be stopped sufficiently to prevent the occurrence of postoperative epidural hematoma. According to the height of the intervertebral space and anatomical morphology, the appropriate size of the trial mould was selected and tested, a suitable Zero-P device was then chosen. After removing the soft tissues from the crushed bone particles, the bone particles mixed with allograft bone were used to fill in the Zero-P device, the device was then inserted into the intervertebral space. Lateral X-ray showed that the Zero-P device fitted tightly to the adjacent vertebral endplate at the appropriate depth. Then the Casper distractor and K-wires were removed, with the access hole being sealed with bone wax. Four self-locking fixation screws (14–16 mm) were inserted successively through the anterior screw channel. After reconfirming the absence of active bleeding and irrigation fluid retention in the surgical area, the incision was closed layer by layer, with or without the placement of the drainage tube, intradermal sutures were used for skin closure, and the incision was then covered with a sterile dressing.

Microscopic ACDF and traditional ACDF procedures

The procedures, such as patient positioning, preoperative preparation and maintenance of operative space, during microscopic ACDF and traditional ACDF were basically the same as MOEA-ACDF. Due to the fact that these two procedures used air as the medium, so an incision of 3 cm for microscopic ACDF and 4 cm for traditional ACDF was made on the right side of the anterior cervical region. The operator held surgical instruments with both hands. Intermittent flushing was carried out during drilling, the assistant held a suction device to suck and clean the irrigation fluid, blood and bone debris from the surgical area, to ensure a clear vision during the procedures. Gelatin sponge, bone wax, and bipolar electrocoagulation hemostatic forcep were used to stop bleeding from bone surface and epidural venous plexus during surgery (Fig. 4). The specific surgical procedures were similar as previously reported [4–9].

Postoperative management

The operation time (the time from initial skin incision to the final closure of the skin incision), postoperative hospital stay, length of skin incision, intraoperative and postoperative complications of each group were recorded. Cephalosporin antibiotics were applied to prevent infection within 24 h after surgery. Patients were encouraged to get out of bed under the protection of cervical collar at 24 h after surgery. The collar was worn for 6–8 weeks, and the drainage tube was removed at 24–48 h after surgery. Neurotrophic drugs were administered to these patients. After surgery, all patients received electroacupuncture stimulation rehabilitation therapy (20 min each time, once a day, 5 to 6 times a week, 2 weeks for 1 course, lasting 2 courses). Movements such as excessive rotation, flexion and extension of the neck should be avoided after 3 months of surgery. All patients were told to receive reexamination every one month before bony fusion was not archived, and every six months thereafter. Related data were collected during reexamination, and the clinical efficacy of these three treatment methods was assessed.

Observation indicators

Cervical Cobb's angle

Cobb's angle is defined as the angle formed by the intersection of two lines drawn perpendicular to the parallel lines extending from the inferior endplates of C2 and C7. Positive values represented anterior convexity, and negative values represented posterior convexity, reflecting the sagittal curvature of the cervical spine.

Cobb angle of fused segment

Cobb angle of fused segment is defined as the angle between the perpendicular lines drawn from the superior and inferior endplates of the fused segment [27], which reflects the sagittal curvature of the fused segment.

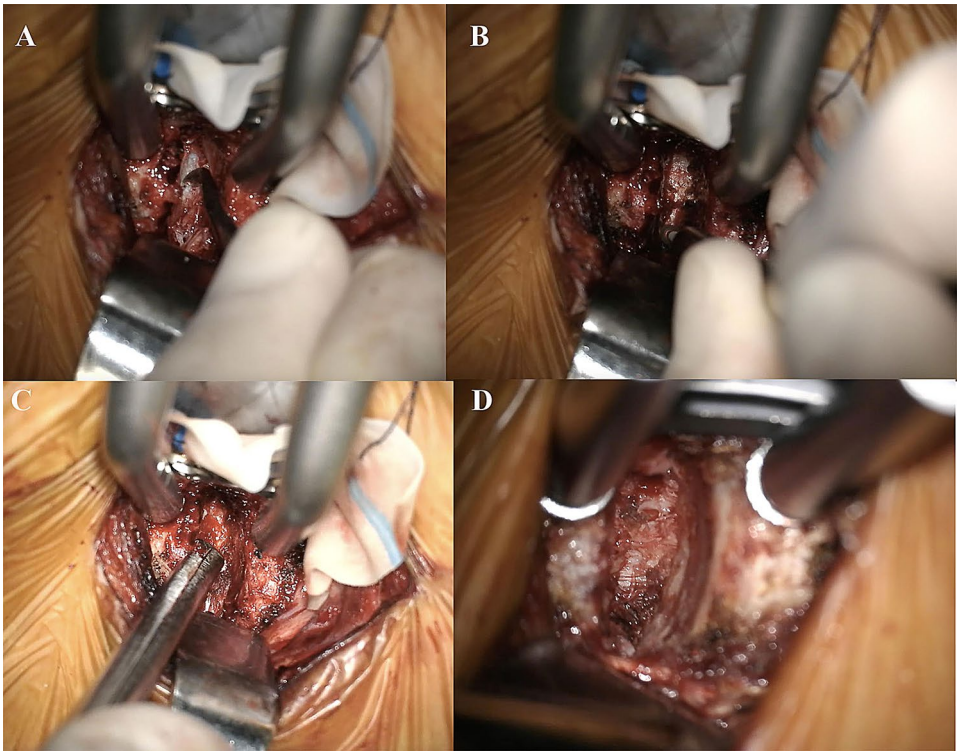

Fig. 4 Intraoperative operations under microscopic view. **A**: Clearing the intervertebral space using a long-handled spatula; **B**: Grinding the osteophytes at the posterior edge of the vertebral body using a high-speed grinding drill; **C**: Removal of the osteophytes at the posterior edge of the vertebral body using a laminar rongeur. **D**: Visualization of posterior longitudinal ligament and the dural sac under microscopic view

Intervertebral space height of the fused segment

Considering that the bone of the anterior and posterior edges of the upper and lower vertebral bodies were removed to varying degrees during surgery, the intervertebral space height of fused segment was defined as the distance between the upper and lower endplates of the middle vertebral body.

Intervertebral fusion status

The existence of intervertebral fusion was assessed according to the following criteria: the presence of bridging bony trabeculae at the fusion device-vertebral body interface; the absence of a radiolucent gap between the fusion device and the upper, lower vertebral bodies; and the absence of motion between the spinous processes on hyperflexion and hyperextension X-rays [28].

VAS score

The VAS is a subjective method of postoperative pain assessment, which was used to assess the degree of neck and upper extremity pain before surgery, at 1 month after surgery, and at the last follow-up. The scale is scored in a range of 0–10 with 0 representing no pain, 1–3 representing mild pain, 4–6 representing moderate pain, and 7–10 representing severe pain. Patients were instructed to choose a single number from the scale that best indicates their level of pain.

JOA score

The JOA score is a 17-point scale, which was applied to assess the neurological function of the cervical spinal cord before surgery, at 1 month after surgery, and at the last follow-up. The JOA score consists of motor function in the four extremities, sensory function in the four extremities and the trunk, and bladder function with a minimum total score of 0 and maximum of 17. A lower score indicates a greater degree of dysfunction. The improvement in cervical spinal cord function after surgery [26] was assessed by calculating JOA recovery rate according to preoperative and postoperative JOA scores. The recovery rate was calculated according to the following formula:

JOA recovery rate (%) = (postoperative JOA score–preoperative JOA score) / (17 - preoperative JOA score) × 100%.

A recovery rate of ≥75% was considered excellent, 50-74% was considered good, 25-49% was considered fair, and <25% was considered poor.

Neck disability index (NDI)

The NDI was applied to assess the functional status of the cervical spine before surgery, at 1 month after surgery, and at the final follow-up visit. The NDI score consists of 10 items related to neck pain and related symptoms, and abilities with respect to activities of daily living (such as work/daily activities), with a maximum of 5 points for each item. A higher score indicates worse function [29]. The NDI was calculated according to the following formula:

NDI (%) = total score/(5×number of items completed) × 100%.

A NDI of 0–20% indicates mild disability, 21-40% indicates moderate disability, 41-60% indicates severe disability, 61-80% indicates very severe disability, and 81-100% indicates complete disability.

Statistical analysis

Data were entered into Excel 2010 and analyzed using SPSS 19.0 software (SPSS Inc., USA). All normally distributed continuous data were presented as mean ± SD, the independent sample t-test was used for comparison between groups, the one-way repeated-measures ANOVA was used to compare the difference between different time points within a group, and a Q-test was used for pairwise comparison when there were statistically significant differences between different time points within a group. Categorical data were compared using the $\chi 2$ test and Fisher's exact test. A two-sided P value of less than 0.05 was considered statistically significant.

Results

General conditions of patients in each group

The operations were successfully completed in all groups, without intraoperative surgical conversion. Postoperative imaging showed that all the internal fixation devices were in good position, the osteophytes at the posterior edge of the vertebral body and the ossified PLL were completely removed, and the spinal cord compression was obviously improved (Fig. 5). The mean follow-up time was 20.5 ± 2.8 months (rang, 16–24 months) in Group A, 20.2 ± 4.3 months (range, 12–26 months) in Group B, and 20.3 ± 3.7 months (range, 13 ~ 24 months) in Group C. There was no statistically significant difference in the baseline data between the three groups in terms of sex, age, BMI, operative segment, and follow-up time ($P > 0.05$, Table 1). There were also no statistically significant differences in the cervical Cobb angle, Cobb angle of the fuse segment, intervertebral space height, VAS scores for neck and upper limb pain, JOA score, and NDI between the three groups before surgery ($P > 0.05$, Table 1), suggesting that the baseline data of these groups were comparable.

Perioperative outcomes

No obvious bleeding was seen in the surgical field of each group during operations with different media being used. No damage to important organs such as esophagus, trachea, and blood vessels were noted in each group. Different degrees of hyperostosis at the anterior edge of the intervertebral space of the operative segment were observed in patients of each group. After removing the degenerated intervertebral discs, osteophyte formation

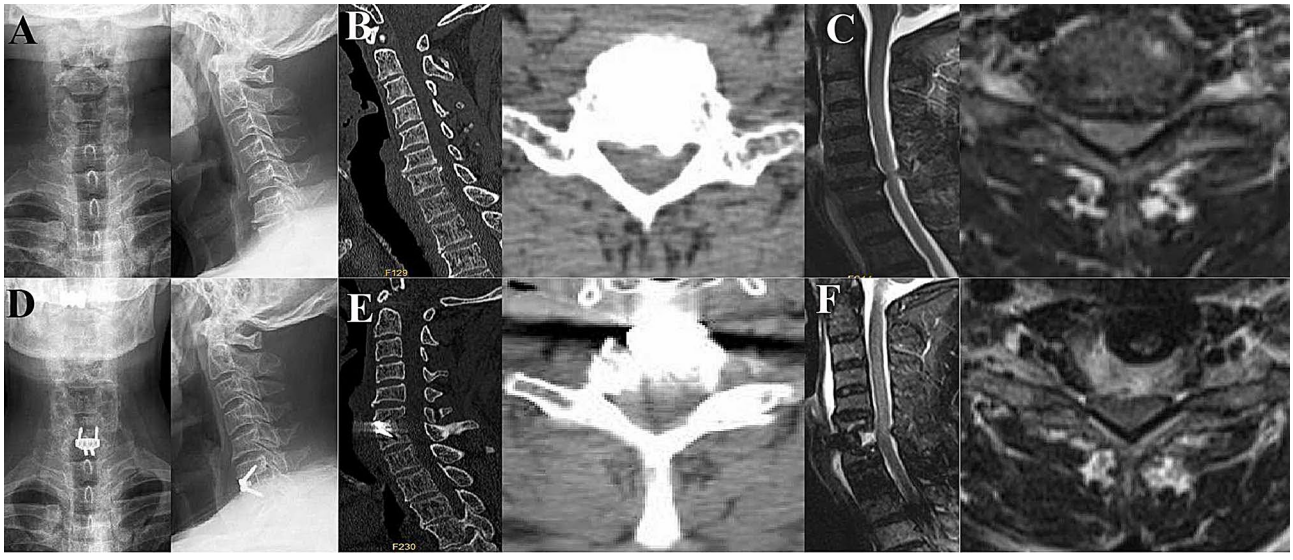

Fig. 5 Pre- and postoperative imaging of a patient with cervical spondylotic myelopathy at the C6, 7 level. **A**: Preoperative x-ray of the cervical spine in AP and lateral view indicated a decrease in the intervertebral space height of the responsible segment. **B**: Preoperative CT revealed osteophyte formation at the anterior and posterior edges of the vertebral body of the responsible segment. **C**: Preoperative MRI showed intervertebral disc herniation at the responsible segment, and anterior spinal cord compression. **D, E, F**: Postoperative x-ray, CT, and MRI revealed a good position of the internal fixation, complete removal of the osteophytes at the anterior and posterior edges of the vertebral body, and improvement in the spinal cord compression

Table 1 Comparison of general information, perioperative, imaging, and clinical outcomes between the three groups

Variables	Group A	Group B	Group C
Number of patients	11	11	11
Sex: male/female (n)	5/6	5/6	5/6
Age (year)	50.7 ± 11.2	50.6 ± 9.8[a]	50.6 ± 9.8[a]
Body mass index (kg/m^2)	24.4 ± 3.0	24.4 ± 3.0[a]	24.4 ± 2.9[a]
Follow-up period (month)	20.5 ± 2.8	20.2 ± 4.3[a]	20.3 ± 3.7[a]
Operation time (min)	94.6 ± 11.9	81.8 ± 8.5[b]	63.3 ± 10.1[b]
Postoperative hospital stay (d)	2.6 ± 0.8	2.7 ± 0.8[a]	2.8 ± 0.9[a]
length of skin incision (cm)	2.1 ± 0.2	2.9 ± 0.2[b]	3.8 ± 0.3[b]
Time taken for bony fusion (month)	5.5 ± 1.4	5.4 ± 1.5[a]	5.6 ± 1.6[a]
Cervical Cobb angle (°)			
Before surgery	7.5 ± 1.8	7.5 ± 1.9[a]	7.5 ± 1.7[a]
One month after surgery	13.9 ± 2.5[c]	13.9 ± 2.1[ac]	14.0 ± 2.6[ac]
Last follow-up	12.7 ± 1.5[c]	13.1 ± 2.0[ac]	12.9 ± 1.7[ac]
Cobb angle of the fused segment (°)			
Before surgery	2.6 ± 1.5	2.5 ± 2.1[a]	2.5 ± 1.7[a]
One month after surgery	4.6 ± 0.9[c]	4.5 ± 0.9[ac]	4.5 ± 0.8[ac]
Last follow-up	4.1 ± 0.7[c]	4.1 ± 0.7[ac]	4.1 ± 0.7[ac]
Intervertebral space height of fused segment (mm)			
Before surgery	4.2 ± 0.6	4.3 ± 0.5[a]	4.3 ± 0.4[a]
One month after surgery	7.9 ± 0.4[c]	7.9 ± 0.5[ac]	7.9 ± 0.5[ac]
Last follow-up	6.5 ± 0.3[c]	6.5 ± 0.4[ac]	6.5 ± 0.4[ac]
VAS score for neck pain (分)			
Before surgery	6.5 ± 0.8	6.5 ± 0.9[a]	6.5 ± 0.9[a]
One month after surgery	2.1 ± 0.7[c]	2.0 ± 0.6[ac]	2.0 ± 0.6[ac]
Last follow-up	1.6 ± 0.5[c]	1.6 ± 0.5[ac]	1.7 ± 0.5[ac]
VAS score for upper extremity pain			
Before surgery	7.1 ± 0.7	7.2 ± 0.8[a]	7.2 ± 1.0[a]
One month after surgery	2.5 ± 0.7[c]	2.4 ± 0.7[ac]	2.4 ± 0.8[ac]
Last follow-up	1.9 ± 0.5[c]	2.0 ± 0.4[ac]	1.9 ± 0.5[ac]
JOA score			
Before surgery	6.8 ± 1.3	6.7 ± 1.1[a]	6.7 ± 1.3[a]
One month after surgery	14.9 ± 0.9[c]	14.5 ± 1.7[ac]	14.4 ± 1.4[ac]
Last follow-up	15.5 ± 0.5[c]	15.5 ± 0.9[ac]	15.5 ± 0.8[ac]
JOA recovery rate (%)	85.9 ± 4.4	85.1 ± 8.9[a]	84.8 ± 7.6[a]
NDI (%)			
Before surgery	36.7 ± 5.1	36.7 ± 5.3[a]	36.8 ± 4.3[a]
One month after surgery	14.7 ± 2.6[c]	14.8 ± 2.7[ac]	14.6 ± 3.0[ac]
Last follow-up	11.5 ± 1.5[c]	11.4 ± 1.4[ac]	12.2 ± 1.7[ac]
Complications	2	2[a]	3[a]

[a] $P > 0.05$, vs. Group A; [b] $P < 0.05$, vs. Group A; [c] $P < 0.05$, vs. Before surgery

at the posterior edge of the vertebral body, ossification or thickening of PLL, and obvious compression of the dural sac were noted. After complete decompression, the dural sac was sufficiently expanded, and returned to its normal shape, without the rupture of the dural sac or cerebrospinal fluid leakage.

Group A had a significantly longer operation time when compared to Groups B and C (94.6 ± 11.9 min vs. 81.8 ± 8.5 min 94.6 ± 11.9 min vs. 63.3 ± 10.1 min, all $P < 0.05$, Table 1). The length of skin incision was significantly shorter in Group A than in Groups B and C (2.1 ± 0.2 cm vs. 2.9 ± 0.2 cm; 2.1 ± 0.2 cm vs. 3.8 ± 0.3 cm, all $P < 0.05$, Table 1). The postoperative hospital stay was 2.6 ± 0.8 d in Group A, 2.6 ± 0.8 d in Group B, 2.8 ± 0.9 d in Group C, no statistically significant difference was found among the three groups ($P > 0.05$, Table 1).

Imaging evaluation outcomes

The status of intervertebral fusion in each group after surgery

All patients in each group had achieved bony fusion during the follow-up period. Bony fusion was achieved at 5.5 ± 1.4 months postoperatively for Group A, 5.4 ± 1.5 months postoperatively for Group B, and 5.6 ± 1.6 months postoperatively for Groups C, respectively, there was no

statistically significant difference in the time taken for bony fusion between the three groups ($P > 0.05$, Table 1).

Cervical Cobb angle

In Group A, the cervical Cobb angle was improved significantly from 7.5°±1.8° before surgery to 13.9°±2.5° at 1 month after surgery, and then to 12.7°±1.5° at the last follow-up ($F = 43.66$, $P < 0.05$, Table 1), while there was no statistically significant difference between 1 month after surgery and the last follow up period ($P > 0.05$, Table 1). In both Groups B and C, the cervical Cobb angle also significantly improved at 1 month after surgery and the last follow up compared with before surgery ($P < 0.05$, Table 1). No significant difference was noted among the three groups before surgery, at 1 month after surgery and the last follow-up ($P > 0.05$, Table 1).

Cobb angle of the fused segment

In Group A, the Cobb angle of fused segment improved significantly at 1 month after surgery and the final follow-up compared with before surgery (4.6°±0.9° vs. 2.6°±1.5°; 4.1°±0.7°vs. 2.6°±1.5°, $F = 14.87$, $P < 0.05$, Table 1), no significant difference was found between 1 month after surgery and the last follow-up ($P > 0.05$, Table 1). In both Groups B, C, the Cobb angle of fused segment also improved significantly at 1 month after surgery and the final follow-up compared with before surgery ($P < 0.05$, Table 1). No significant difference was noted among the three groups before surgery, at 1 month after surgery and the final follow-up ($P > 0.05$, Table 1).

Intervertebral space height of fused segment

In Group A, the intervertebral space height of fused segment improved significantly from 4.2 ± 0.6 mm before surgery to 7.9 ± 0.4 mm at 1 month after surgery, and then to 6.5 ± 0.3 mm at the last follow up ($F = 242.04$, $P<0.05$, Table 1), and there were also significant differences between 1 month after surgery and the last follow-up ($P<0.05$, Table 1). The intervertebral space height of fused segment were also significantly improved at 1 month after surgery and the last follow-up compared with before surgery in both Groups B, C ($P < 0.05$, Table 1). No significant difference was found among the three groups before surgery, at 1 month after surgery and the final follow-up ($P > 0.05$, Table 1).

Clinical outcomes

VAS score for neck pain

In Group A, neck pain was obviously relieved after surgery, the VAS score for neck pain decreased significantly from 6.5 ± 0.8 before surgery to 2.1 ± 0.7 at 1 month after surgery, and then to 1.6 ± 0.5 at the last follow-up ($F = 187.52$, $P < 0.05$, Table 1), and there was no statistically significant difference between 1 month after surgery and the last follow-up ($P > 0.05$, Table 1). The VAS score for neck pain were also significantly improved at 1 month after surgery and the last follow-up compared with before surgery in both Groups B and C ($P < 0.05$, Table 1). There was no significance difference among the three groups at the same time points ($P > 0.05$, Table 1).

VAS score for upper extremity pain

In Group A, upper extremity pain was obviously relieved after surgery, the VAS score for upper extremity pain decreased significantly from 7.1 ± 0.7 before surgery to 2.5 ± 0.7 at 1 month after surgery, and then to 1.9 ± 0.5 at the last follow-up ($F = 282.98$, $P < 0.05$, Table 1), and there was no statistically significant difference between 1 month after surgery and the last follow-up ($P > 0.05$, Table 1). In both Groups B and C, the VAS score for upper extremity pain at 1 month after surgery and the last follow-up were also significantly improved compared with before surgery ($P < 0.05$, Table 1). There was no statistically significant difference among the three groups at the same time points ($P > 0.05$, Table 1).

JOA score

In Group A, obvious recovery of neurological function of the cervical spinal cord was observed. The JOA score was significantly improved from 6.8 ± 1.3 before surgery to 14.9 ± 0.9 at 1 month after surgery, and then to 15.5 ± 0.5 at the last follow-up ($F = 438.42$, $P < 0.05$, Table 1), while no statistically significant difference was fond between 1 month after surgery and the last follow-up ($P > 0.05$, Table 1). The JOA recovery rate at the final follow-up was 85.9%±4.4% in Group A. In both Groups B and C, the JOA scores significantly improved at 1 month after surgery and the last follow-up compared with before surgery ($P < 0.05$, Table 1). The JOA recovery rate was classified as excellent in all groups, which did not differ significantly among the three groups at the same time points (all $P > 0.05$, Table 1).

NDI

In Group A, the preoperative NDI was 36.7 ± 5.1, indicating that patients had moderate disability before surgery. The NDI was reduced to 14.7% ± 2.6% at 1 month after surgery, and 11.5% ± 1.5% at the final follow-up, and the difference was statistically significant ($F = 163.66$, $P < 0.05$, Table 1). And statistically significant differences were also found between 1 month after surgery and the final follow-up ($P < 0.05$, Table 1). In both Groups B and C, the NDI also significantly improved at 1 month after surgery and the last follow-up compared with before surgery ($P < 0.05$, Table 1). The NDI was not different significantly among groups before surgery, at 1 month after surgery, and the last follow-up ($P > 0.05$, Table 1).

Complications

Complications such as recurrent laryngeal nerve and spinal cord injuries, arterial rupture, tracheo-esophageal perforation, cerebrospinal fluid leakage, incision infection, did not occur in either group. None of the patients experienced failure of internal fixation, such as screw loosening, displacement and subsidence of the fusion device.

In Group A, 2 (20.0%, 2/10) patients developed postoperative complications, including 1 case of dysphagia and 1 case of pain in bilateral scapular region. In Group B, 2 (20.0%, 2/10) patients developed postoperative complications, including 1 case of dysphagia and 1 case of stabbing pain in the right upper extremity. In Group C, the postoperative complications were noted in 3 (30.0%, 3/10) patients, including 2 cases of dysphagia and 1 case of pain in the right scapular region. There was no statistically significant difference in the complication rates among the three groups ($P > 0.05$, Table 1). Patients who had dysphagia received conservative treatments (such as reducing edema and avoiding spicy foods), and dysphagia disappeared completely within 3 weeks after treatment. Patients who had pain in the scapular region and upper extremity received symptomatic treatments, such as nonsteroidal anti-inflammatory analgesic drugs, neurotoxic drugs, electroacupuncture stimulation, and the symptoms completely disappeared after 2 weeks.

Discussion

Feasibility of MOEA-ACDF in the treatment of CSM

Deng et al. [30] proposed that due to the complex inherent anatomical structure of the anterior cervical spine, the anterior approach is inevitably accompanied by damage to important organs such as large blood vessels and the esophagus. At the same time, the irrigation fluid used in endoscopy can flow into the surrounding spaces, such as the mediastinum along the fascial space, leading to complications such as neck swelling and even mediastinal effusion, which is the main obstacle limiting the application of endoscopic technology in anterior cervical surgery. Therefore, endoscopic technique is more likely to be applied in posterior cervical surgery. However, when the spinal cord compressive factor mainly comes from the anterior aspect of the spinal cord, such as protruding nucleus pulposus, proliferative osteophytes, or focal ossified PLL, it is often difficult to achieve ideal treatment results using indirect decompression through the posterior cervical approach. Direct removal of spinal cord compressive factors through the anterior cervical approach is often the best choice [1–3, 6]. MOEA-ACDF is a technique originated from the UBE technique. It achieves the decompression, fusion, and fixation of the anterior spinal cord through constructing a complete endoscopic imaging system and an irrigation fluid circulation device in the anterior cervical spine. This technology was successfully performed in our department since May 2020. Based on technical and anatomical levels, the feasibility of using MOEA-ACDF for the treatment of CSM mainly includes the following points: Firstly, our department has rich experience in the use of traditional ACDF, microscopic ACDF, and UBE technique, which have laid a solid and necessary technical foundation for the successful implementation of MOEA-ACDF. Secondly, previous research reports on APECD and endoscopic ACDF provide important references for the use of MOEA-ACDF in the treatment of CSM [11–12, 18, 19, 20]. Thirdly, there is a natural anatomical space between the esophagus and the vascular sheath in the anterior cervical spine, creating an excellent surgical pathway for various types of ACDF [6]. At the same time, during MOEA-ACDF surgery, we can construct a surgical area with a diameter of approximately 2 cm, without needing assistance from assistants while effectively avoiding the entry of soft tissues such as the esophagus into the surgical path. This method reduces the risk of damage to organs such as the recurrent laryngeal nerve and esophagus. Moreover, the open operative space ensures smooth flow of irrigation fluid, reduces irrigation fluid pressure within the surgical area, and prevents irrigation fluid from infiltrating into tissue spaces outside the surgical area.

The short-term clinical efficacy and technical advantages of MOEA-ACDF for the treatment of CSM

Most scholars believe that both ACDF and anterior cervical corpectomy and fusion (ACCF) can achieve satisfactory results in the treatment of CSM. However, ACDF is associated with less bleeding and a lower incidence of complications such as fusion cage displacement and spinal cord nerve injury [31, 32]. Yu et al. [33] reported that both ACDF and ACCF have a definite therapeutic effect on CSM, maintaining cervical curvature and improving sagittal balance parameters of the cervical spine. However, ACDF is more ideal for patients with a large preoperative T1 tilt angle. In terms of fusion devices used in ACDF surgery, Tsalimas et al. [34], Zhao et al. [26], and Zhang et al. [35] believed that the use of Zero-P devices during ACDF does not produce obvious differences in correcting cervical physiological curvature and maintaining cervical stability when compared with use of titanium plate combined with fusion cages. Moreover, the use of Zero-P devices requires shorter surgical time, produces less bleeding, and leads to a lower incidence of complications such as adjacent segment degeneration and swallowing difficulties.

The results of this study are similar to previous studies. Our results revealed that the JOA scores at 1 month after surgery and at the final follow-up were significantly

lower compared with pre-surgical levels, and the JOA recovery rate at the final follow-up was classified as excellent (>75%) in all groups. This result indicates a marked improvement in spinal cord nerve function. Following surgery, the VAS score for neck and upper limb pain significantly decreased, and with the extension of follow-up time, the improvement in neck and upper limb pain can be sustained. Additionally, the NDI remarkably decreased after surgery, patients were categorized as moderate disability before surgery, and mild disability after surgery. Furthermore, with prolonged follow-up, the functional status of the cervical spine continued to improve. In terms of imaging parameters, the Cobb angle of the cervical spine, the Cobb angle of fused segment, and the intervertebral space height of fused segment remarkably increased after surgery when compared with pre-surgical levels. The physiological curvature of the cervical spine was significantly improved, and all patients achieved bony fusion during the follow-up period. Furthermore, no case experienced internal fixation failures such as screw loosening or fusion device displacement. Only the intervertebral space height of fused segment decreased significantly in the last follow-up when compared with 1 month post-surgery ($P<0.05$). However, this difference did not result in any clinical symptoms. This was likely due to the process of matching and fitting between the fusion cage and the bone endplate. Collectively, these findings demonstrate that for the treatment of CSM, MOEA-ACDF with the use of Zero-P device for reconstruction of the cervical spine following decompression can effectively restore the physiological curvature of the cervical spine, with firm fixation, excellent stability, high intervertebral fusion rates, and combined with postoperative rehabilitation therapy such as electroacupuncture stimulation, thus achieving satisfactory short-term clinical outcomes. For the selection of indications for MOEA-ACDF, we believe that it is essentially the same as traditional ACDF or microscopic ACDF, and is primarily suitable for patients with CSM or cervical spondylotic radiculopathy, focal OPLL, or traumatic cervical dislocation.

Regarding whether endoscopic spine surgery under the water medium can achieve the same or better therapeutic effects compared with traditional open spine surgery or microsurgery under the air medium, scholars believe that surgeries under different media can both achieve good therapeutic effects on CSM [4–9, 21–25, 36]. However, endoscopic vision under the water medium is clearer, the operation is safer, and tissue damage is milder compared with endoscopic vision under the air medium. In this study, the comparison of the clinical efficacy of MOEA-ACDF and microscopic ACDF, traditional ACDF obtained similar results as reported in previous studies. Our results showed that at 1 month after surgery and at the last follow up, the clinical indicators and imaging parameters were both remarkably improved compared with before surgery. And there were no significant differences among the three groups. MOEA-ACDF required a smaller incision length. However, a longer operation time was required because of the relatively short period of time that MOEA-ACDF has been implemented and unfamiliarity with the surgical process. Nevertheless, the postoperative hospital stay and the incidence of complications did not increase after MOEA-ACDF. Based on previous studies and our practical surgical experience, we summarize the advantages of MOEA-ACDF as follows: (1) Upon mastering the key points of endoscopic procedures and traditional ACDF techniques, the learning curve of MOEA-ACDF is flat. (2) During MOEA-ACDF, there is no need to excessively stretch the anterior neck soft tissues, surgeon can create the operating field using devices such as a Casper distractor, allowing the surgeon to independently complete the entire surgical process, reducing safety risks when multiple surgeons work together and simplifying the layout of the operating room. (3) Continuous circulation of water medium can reduce the risk of surgical infection, decrease the heat generated during use of radiofrequency electrodes and grinding drills, reduce the likelihood of thermal burns to the soft tissue of the neck, and avoid nerve and spinal cord damage caused by local heat transfer. (4) During MOEA-ACDF, the endoscopic field of view under the water medium is clearer compared to that under the air medium, leading to excellent hemostasis effect. Bone debris that is grinded off during grinding can be flushed out of the surgical field with flowing irrigation fluid, making it easy to observe various anatomical structures. During MOEA-ACDF, the endoscopic lens can be inserted into the narrow intervertebral space, which makes it easier to observe the morphology of the osteophytes at the posterior edge of the vertebral body, distinguish the dural sac and PLL, and facilitate the removal of large osteophytes or ossified PLL that are difficult to remove during microscopic ACDF or traditional ACDF. MOEA-ACDF is more accurate, more efficient, and safer. (5) During MOEA-ACDF, the preparation of the fusion interface can be directly observed to avoid damaging the bony endplate, ensuring complete removal of the cartilage endplate. By rotating 30-degree arthroscopic view, the degree of sneak decompression in the narrow space at the posterior edge of the vertebral body can be understood, ensuring a sufficient decompression effect.

Key operating points and precautions for MOEA-ACDF technique

Fine operation and detailed handling are the keys to successful surgery. Based on our experience in performing MOEA-ACDF, the following points should be noted

during MOEA-ACDF: (1) Due to the small size of the surgical incision, any deviation from the incision can easily increase the difficulty of the surgery, often requiring the extension of the surgical incision or excessive stretching of the anterior neck soft tissues, which can lead to unnecessary damage. Therefore, accurate incision positioning should be ensured before surgery. (2) During MOEA-ACDF at C3-4 segment, mandibular occlusion often interferes with instrument operation, which requires that the patient's neck be adjusted before surgery to maintain a moderate extension state to obtain better operative space. If the patient's neck is short and thick, and the spinal cord is severely compressed, it is difficult to reduce mandibular interference by adjusting the body position. In this case, it is recommended to switch to microscopic ACDF or traditional ACDF at the C3-4 segment. The C2-3 segment is located closer to the head end, making it difficult to open and fix the distractor, making it difficult to create a working channel perpendicular to the diseased intervertebral space, affecting surgical operation, and the irrigation fluid is prone to retain in the retropharyngeal space. Therefore, MOEA-ACDF at C2-3 segment is not recommended. (3) Regarding when the endoscopic system can be introduced, we believe that the main function and advantage of the endoscopic system lie in high-definition and clear visualization, which can display the areas that are difficult to observe under the air medium. When the intervertebral space is exposed, the endoscopic system can be introduced at a Casper distractor is inserted. After the fusion cage is inserted, the endoscopic system can be withdrawn. (4) Regarding the selection of endoscopic lenses, we believe that both 0-degree and 30-degree lenses have their respective advantages. The 0-degree lens, without field of view deviation, can directly view the deep intervertebral disc, the PLL, and the dural sac in the narrow space. Meanwhile, the 30-degree lens can obtain a wider angle of view by rotating the lens. It is recommended to prepare both types of lenses during surgery and replace them at any time according to specific needs to ensure the smooth progress of the surgery. (5) Proper hemostasis is always the primary concern during endoscopic procedures, and controlled hypotension remains the key during surgery. Under the premise of ensuring that essential tissues and organs receive adequate blood flow, ideal blood pressure control during surgery is to maintain the systolic blood pressure at 90–100 mmHg, or reduced the average arterial pressure to 60–70 mmHg (for those with concurrent hypertension, the blood pressure should be reduced to 70% of the original average arterial pressure). During surgery, bleeding from the venous plexus can be controlled using radiofrequency or gelatin sponges. However, during MOEA-ACDF, managing bleeding from the cut surface of the cancellous bone can be more challenging. This can be achieved through the use of radiofrequency or applying bone wax to the drill bit, as well as via the thermal effect during high-speed drilling and the direct filling of bone wax to maintain a clear surgical field. The use of tranexamic acid prior to surgery also demonstrates promising hemostatic effects [37]. (6) It is not recommended to increase the water pressure for hemostasis purposes. The specific intraoperative water pressure should be maintained. Maintaining the perfusion pressure below 30 mmHg is recommended [23–25]. (7) Regarding the selection of drill bit diameter, larger bits are difficult to enter the intervertebral space, and smaller bits can affect the work efficiency. We suggest a 2–4 mm grinding bit can be selected, which can balances work efficiency and ease of use. It is important to avoid using long axis grinding drills, ensuring that the working parts of the grinding drill, including the drill bit and connecting shaft, are located under the endoscopic view and falls into the intervertebral space. This minimizes the risk of neck soft tissue entanglement that can cause unforeseeable severe consequences during surgery. (8) Patients were given rehabilitation physiotherapy such as electroacupuncture stimulation to accelerate the rehabilitation of spinal cord nerve function after surgery.

Limitations and future research direction

There are still some limitations in this study. Firstly, at the technical level, there is a lack of specialized instruments for the MOEA-ACDF procedures. For example, the anterior distraction system mainly relies on a combination of Kirschner wires, S-shaped hooks, and Casper distractor. Although these instruments are relatively easy to obtain, the reliability cannot be fully ensured. Additionally, some instruments such as vertebral lamina rongeurs, grinding drills can be too large, which can interfere with the endoscope in narrow operative spaces. These issues need to be addressed urgently. Secondly, the study only included patients single-level CSM, further research is required to verify whether patients with multi-level CSM can achieve the same treatment results after treatment with MOEA-ACDF. Furthermore, this study is a single-center retrospective study with a small sample size. Only short-term follow-up has been conducted on the enrolled patients, lacking evaluation of long-term efficacy. Therefore, future prospective randomized controlled studies with larger sample sizes from multiple centers and long-term follow-up are required to strengthen the credibility of research findings.

Regarding the future research direction of MOEA-ACDF technology, we believe that the application of navigation technology may have great potential and practicability. Real-time navigation systems are valuable in guiding the complete removal of osteophytes at the posterior margin of the vertebral body. During

surgery, optical or electromagnetic navigation systems can be used to track the position and direction of surgical instruments in real time, providing accurate intraoperative navigation, which can ensure the safety and effectiveness of surgery.

In conclusion, as a novel minimally invasive technique in the field of cervical spine surgery, MOEA-ACDF has demonstrated short-term clinical efficacy that is comparable to that of microscopic ACDF and traditional ACDF in treating CSM. Because of its unique technical advantages, it is anticipated that MOEA-ACDF will become the supplementary surgical procedure in anterior cervical spine surgery after the improvement of relevant instruments and enhancement of research evidence. MOEA-ACDF holds great promise for clinical promotion.

Abbreviations

ACDF	Anterior cervical discectomy and fusion
CSM	Cervical spondylotic myelopathy
UBE	Unilateral biportal endoscopy
MOEA-ACDF	Mini-open endoscope assisted anterior cervical discectomy and fusion
OPLL	Ossification of posterior longitudinal ligament
Zero-p	Zero-profile device
VAS	Visual analogue scale
JOA	Japanese orthopedic association score
NDI	Neck disability index
APECD	Anterior percutaneous endoscopic cervical discectomy
AP	Anteroposterior
PLL	Posterior longitudinal ligaments

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Author contributions
HZ was a major contributor in writing the manuscript. QW, BZ, LC, JJ helped in completing operation and collection of the data. DT Performed the operation. LC, YZ analyzed the data and helped in revision of the paper. All authors read and approved the final manuscript.

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Data availability
All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate
This study was performed in line with the principles of the Declaration of Helsinki, and was approved by the Ethics Committee of the Second Affiliated Hospital of Anhui Medical University (sl-xjs2019-001). Informed consent was obtained from all individual participants included in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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