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颈椎前路榫卯截骨还纳融合术治疗后纵韧带骨化症的临床疗效

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[摘 要] 目的：对于伴有脊髓损害的节段型颈椎后纵韧带骨化症(ossification of cervical posterior longitudinal ligament，OPLL)，颈椎前路椎体次全切除融合术(anterior cervical corpectomy and fusion，ACCF)可通过切除大部分受累椎体直接减压，但术后易出现钛网沉降、颈椎生理曲度丢失、植骨融合不佳等重建相关问题。探讨1种基于生物学重建及传统结构力学原理设计的颈椎前路榫卯截骨还纳融合术(anterior cervical mortise-tenon corpectomy and fusion，ACMTF)治疗节段型OPLL的临床疗效，并与ACCF进行对比分析。**方法：**回顾性分析2020年1月至2024年5月在中南大学湘雅医院脊柱外科接受颈椎前路手术治疗的节段型OPLL患者。其中，30例接受了ACMTF治疗(ACMTF组)，同时通过倾向性评分匹配按1∶1的比例从同期接受传统ACCF治疗的患者中匹配30例作为对照(ACCF组)。ACMTF组采用超声骨刀行椎体前部V形截骨，切除后方骨化灶后将V形骨块原位还纳，形成榫卯结构，并联合椎间融合器与前路钛板进行固定；ACCF组行传统椎体次全切除及钛网重建。对比2组患者的手术时间、术中出血量、围手术期和术后随访并发症发生情况，以及术前与术后不同随访时间点的日本骨科协会(Japanese Orthopaedic Association，JOA)评分、JOA评分改善率、颈椎功能障碍指数(neck disability index，NDI)、视觉模拟评分法(Visual Analogue Scale，VAS)评分；通过影像学检查评估并对比2组的椎管侵占率(occupation ratio，OR)、脊髓有效空间(space available for the spinal cord，SAC)、植骨融合率、植入物沉降率及颈椎前凸角度的变化。**结果：**2组患者经倾向性评分匹配后，性别、年龄、病程、体重指数(body mass index，BMI)、手术节段等基线资料的差异均无统计学意义(均P>0.05)，具有良好的可比性。ACMTF组平均手术时间为164.5 min，长于ACCF组的128.4 min，差异有统计学意义(P<0.05)；2组术中平均出血量分别为385.9 mL、352.4 mL，差异无统计学意义(P>0.05)。末次随访时，2组的JOA评分、VAS评分及NDI均较术前显著改善(均P<0.05)，组间同时间点各项指标及JOA评分的差异均无统计学意义(均P>0.05)。术后2组OR均较术前大幅下降，SAC均较术前显著增加(均P<0.05)，但组间差异无统计学意义(P>0.05)。术后12个月，ACMTF组的植骨融合率为100%，ACCF组为93.3%，组间差异无统计学意义(P>0.05)；ACMTF组未发生植入物严重沉降，显著低于ACCF组的20.0%，差异有统计学意义(P<0.05)。术后6个月及12个月，ACMTF组的颈椎前凸角度维持效果显著优于ACCF组，差异有统计学意义(P<0.05)。并发症方面，2组各发生1例脑脊液漏，发生率均为3.3%，经腰大池引流及局部加压包扎后愈合；ACCF组出现6例钛网严重沉降，患者均无明显临床症状，未行翻修手术；2组均未发生其他严重并发症。**结论：**ACMTF治疗节段型OPLL可获得与ACCF相当的神经减压、神经功能恢复、疼痛症状改善效果。ACMTF基于榫卯原理的自体骨块原位还纳设计可实现术区稳定的力学嵌合，有效预防移植物严重沉降的发生，更好地维持颈椎生理曲度，同时可实现确切的骨性融合，是治疗节段型OPLL安全有效的前路生物学重建策略。

[关键词] 颈椎前路手术；自体骨移植；椎体切除融合；后纵韧带骨化；节段型颈椎后纵韧带骨化症；榫卯截骨；生物学重建

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Clinical efficacy of anterior cervical mortise-tenon corpectomy and fusion for the treatment of ossification of the posterior longitudinal ligament

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ABSTRACT

Objective: For the segmental ossification of cervical posterior longitudinal ligament (OPLL) accompanied by spinal cord compression, anterior cervical corpectomy and fusion (ACCF) can achieve direct decompression through removal of most of the involved vertebral body. However, reconstruction-related complications such as titanium mesh cage subsidence, loss of cervical lordosis, and poor bone fusion are common after surgery. This study aims to investigate the clinical efficacy of a novel anterior cervical mortise-tenon corpectomy and fusion (ACMTF) technique, designed based on principles of biological reconstruction and traditional structural mechanics, for the treatment of segmental cervical OPLL, and to compare its outcomes with those of conventional ACCF.

Methods: A retrospective analysis was conducted on patients with segmental cervical OPLL who underwent anterior surgery in the Department of Spinal Surgery, Xiangya Hospital, Central South University, between January 2020 and May 2024. Among them, 30 patients underwent ACMTF (ACMTF group). Using propensity score matching at a 1∶1 ratio, 30 patients who underwent conventional ACCF during the same period were selected as controls (ACCF group). In the ACMTF group, an ultrasonic osteotome was used to perform V-shaped osteotomy of the anterior vertebral body. After removal of the posterior ossified lesion, the V-shaped autologous bone block was restored in situ to form a mortise-tenon structure and fixed with an intervertebral fusion cage and anterior titanium plate. The ACCF group underwent conventional subtotal corpectomy and titanium mesh reconstruction. Surgical time, intraoperative blood loss, perioperative and follow-up complications, and Japanese Orthopaedic Association (JOA) score, JOA recovery rate, Neck Disability Index (NDI), and Visual Analogue Scale (VAS) score at different follow-up time points before and after surgery were compared between the two groups. Imaging examinations were used to evaluate and compare occupation ratio (OR), space available for the spinal cord (SAC), fusion rate, implant subsidence rate, and changes in cervical lordosis angle.

Results: After propensity score matching, there were no statistically significant differences between the 2 groups in baseline characteristics including sex, age, disease duration, body mass index, and surgical segments (all $P>0.05$), indicating good comparability. The mean operative time in the ACMTF group was 164.5 minutes, which was significantly longer

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than 128.4 minutes in the ACCF group (P<0.05). The mean intraoperative blood loss was 385.9 mL and 352.4 mL in the ACMTF and ACCF groups, respectively, with no statistically significant difference (P>0.05). At the final follow-up, JOA score, VAS score, and NDI in both groups were significantly improved compared with preoperative values (all P<0.05), while no statistically significant differences were found between the groups at the same time points (P>0.05). Postoperatively, OR was significantly decreased and SAC was significantly increased in both groups compared with preoperative levels (all P<0.05), with no statistically significant intergroup differences (P>0.05). At 12 months after surgery, the fusion rate was 100% in the ACMTF group and 93.3% in the ACCF group, with no statistically significant difference (P>0.05). No severe implant subsidence occurred in the ACMTF group, which was significantly lower than the 20.0% incidence in the ACCF group (P<0.05). At 6 and 12 months postoperatively, maintenance of cervical lordosis angle was significantly better in the ACMTF group than in the ACCF group (P<0.05). Regarding complications, one case of cerebrospinal fluid leakage occurred in each group (3.3%), both of which healed after lumbar cistern drainage and local compressive dressing. Six cases of severe titanium mesh subsidence occurred in the ACCF group, but none of the patients showed obvious clinical symptoms or required revision surgery. No other severe complications occurred in either group.

Conclusion: ACMTF for segmental cervical OPLL can achieve neurological decompression, neurological recovery, and pain relief comparable to those of ACCF. The in situ restoration design of the autologous bone block based on the mortise-tenon principle enables stable mechanical interlocking at the surgical site, effectively prevents severe graft subsidence, better maintains physiological cervical curvature, and achieves reliable bony fusion. Therefore, ACMTF represents a safe and effective anterior biological reconstruction strategy for the treatment of segmental cervical OPLL.

KEY WORDS anterior cervical surgery; autologous bone graft; corpectomy and fusion; ossification of the posterior longitudinal ligament; segmental ossification of cervical posterior longitudinal ligament; mortise-tenon osteotomy; biological reconstruction

颈椎后纵韧带骨化症(ossification of cervical posterior longitudinal ligament，OPLL)是一种以颈椎后纵韧带异常钙化、骨化为特征的退行性脊柱疾病，其病理产物直接压迫脊髓腹侧，导致椎管狭窄，进而引发四肢麻木、精细动作障碍、步态不稳等症状，严重者可致瘫痪[1]。流行病学数据[2-4]显示，OPLL在亚洲人群，尤其在日本、中国和韩国人群中的患病率显著高于欧美人群。但OPLL的病因尚不明确，可能与遗传和环境因素相关。影像学上，OPLL在X线和CT上表现为高密度骨化病变，按照病变连续程度可分为连续型、节段型、混合型和局限型[5-6]。MRI是术前评估脊髓压迫程度和预测预后的重要手段[2]。对于伴有进行性脊髓损害的OPLL，手术减压是唯一有效的治疗方法[3, 7]。手术策略主要分为前路、后路及前后联合入路。选择何种入路通常取决于骨化灶的形态(连续型、节段型、混合型或局限型)、椎管侵占率(occupation ratio，OR)、颈椎矢状面序列和累及节段的数量[2-3, 8]。

针对节段型OPLL(即骨化灶主要位于椎体后方，未跨越椎间盘连成一片)，前路手术因其能直接切除致压物、解除脊髓腹侧压迫并利于恢复颈椎前凸曲度而备受推崇[9]。颈椎前路椎体次全切除融合术(anterior cervical corpectomy and fusion，ACCF)是目前治疗节段型OPLL的主流术式，通过切除受累椎体的大部分，可为切除后方骨化灶提供宽敞的视野，减压效果确切。然而，ACCF面临着严峻的重建难题。切除椎体后形成的长节段缺损通常使用钛网进行重建。由于钛网是刚性金属，与人体松质骨存在

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弹性模量失配，加之钛网端面与椎体终板呈点状接触，实际接触面积有限，术后极易发生应力遮挡和钛网沉降[10-12]。前路椎间盘切除融合术(anterior cervical discectomy and fusion，ACDF)虽具微创优势且并发症较少，但其手术视野受限于椎间隙，难以彻底切除向椎体后方广泛延伸的骨化灶，强行减压极易损伤脊髓[13-14]。前路可控前移融合术(anterior controllable antedisplacement and fusion，ACAF)作为一种新技术，通过提拉椎体-骨化复合物实现间接减压，在保留后纵韧带完整性的同时扩大椎管。但该技术操作繁琐，需要特殊的导向器械，且骨化灶并未被切除，存在术后骨化继续进展的潜在风险[15]。后路手术如开放式椎管成形术和椎板切除融合术适用于混合型或连续型OPLL，但对于节段型病灶效果有限[1, 16]。椎管成形术虽可扩大脊髓后漂空间，但无法去除前方病变，且易并发C_5麻痹和颈肩痛等问题[9, 17-19]；椎板切除融合术减压彻底但牺牲后路组织，且术后颈椎活动度丧失会增加相邻节段退变的风险[13]。

因此，本研究提出了一种基于生物学重建理念的颈椎前路榫卯截骨还纳融合术(anterior cervical mortise-tenon corpectomy and fusion，ACMTF)。该术式的核心理念源自中国传统建筑中的“榫卯”结构，通过凹凸嵌合形成稳定的力学连接。在ACMTF中，采用V形截骨获取自体骨块，并在完成减压后将其原位还纳，形成类似“榫卯”结构的匹配界面。该设计可实现良好的初始稳定性，并通过自体骨的生物学特性促进骨性融合，同时增加骨接触面积，有助于降低移植物沉降风险。基于上述理论优势，本研究采用回顾性队列研究设计，将接受ACMTF的患者与同期接受传统ACCF的患者进行对比分析，以评估其临床疗效。

1 对象与方法

1.1 伦理声明

本研究已获得中南大学湘雅医院伦理审查委员会批准(审批号：2019096490)，所有患者术前均已签署手术知情同意书。

1.2 对象

本研究回顾性筛选了2020年1月至2024年5月期间，因节段型颈椎OPLL在中南大学湘雅医院脊柱外科由同一高年资脊柱外科团队进行颈椎前路减压融合手术(ACMTF/ACCF)的患者。

纳入标准：1)节段型OPLL累及椎体数≤3个；2)存在脊髓压迫所致脊髓病；3)骨化灶基底相对较窄，适合行V形截骨或椎体次全切除；4)无严重硬膜骨化或“双轨征”等提示硬膜严重粘连的影像学证据；5)随访资料完整，随访时间≥12个月。

排除标准：1)OPLL椎管OR>70%(此类巨大骨化灶通常需更广泛的切除或后路手术)；2)既往有颈椎手术史；3)合并严重骨质疏松症(T值<−2.5)或广泛的颈椎不稳定；4)合并活动性感染、肿瘤或严重的全身性疾病，无法耐受手术。

本研究最终共纳入60例患者。其中，ACMTF组纳入了研究期间内符合各项纳入和排除标准的30例连续病例。为了最大限度地控制潜在的混杂偏倚因素，采用倾向性评分匹配方法，从同期接受传统ACCF手术的患者数据库中，按照1∶1的比例为ACMTF组严格匹配了30例对照病例。匹配变量包括：年龄、性别、体重指数(body mass index，BMI)、术前日本骨科学会(Japanese Orthopaedic Association，JOA)评分、椎管OR及手术节段。

1.3 手术方法

1.3.1 ACMTF组手术步骤

显露与定位：全身麻醉下，取仰卧位，颈部略后伸。采用经典的右侧Smith-Robinson切口，逐层分离进入椎前间隙，显露目标椎体，在C形臂X线机透视下定位。

V形截骨(制备榫头)：切除目标椎体上下的椎间盘及终板软骨。使用超声骨刀在椎体前部行双侧V形截骨。截骨线始于前皮质中线旁开0.5~1.0 cm处，向内单侧倾斜20°~30°向后延伸，汇聚至后纵韧带基底前方，截骨深度约为椎体前后径的4/5。保持V形骨块的完整性，将其取出并用湿盐水纱布包裹备用(作为自体榫头)。

直视减压：取出V形骨块后，形成一个宽敞的倒三角形骨槽。通过此骨槽及上下椎间隙，利用高速磨钻、超声骨刀和枪状咬骨钳，精细打磨并切除椎体后壁残留骨质及后方的骨化灶。减压范围外侧达钩椎关节内侧缘，深度直至后纵韧带切除、硬膜囊充分膨起并恢复搏动。

榫卯还纳与固定：修整取下的V形骨块，将其原位植入骨槽(卯眼)中。由于V形结构的几何特性，骨块在受到前方钛板压力时会自锁，不会向后移位。在上下椎间隙植入填充有人工骨或自体骨颗粒的碳纤维或聚醚醚酮(polyether ether ketone，PEEK)融合器以维持椎间高度。最后，根据颈椎生理曲度预弯钛合金钢板，行前路钛板螺钉内固定，对还纳骨块进行加压固定(图1和2)。

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1.3.2 ACCF组手术步骤

椎体次全切：显露同上。切除上下椎间盘后，使用咬骨钳和高速磨钻切除椎体中部的大部分骨质，保留两侧侧壁以维持部分稳定性，形成宽度约15~18 mm的骨槽。

减压：打磨并切除椎体后壁及后方骨化灶，直至硬膜囊完全减压。

重建：测量减压后的缺损长度。将钛网裁剪为合适长度，将切除下来的椎体碎骨(自体骨)剪碎后紧密填充于钛网内。

固定：对头尾端椎体施加牵引，将填好骨的钛网敲入缺损区。透视确认位置满意后，安装前路锁定钛板系统进行固定。

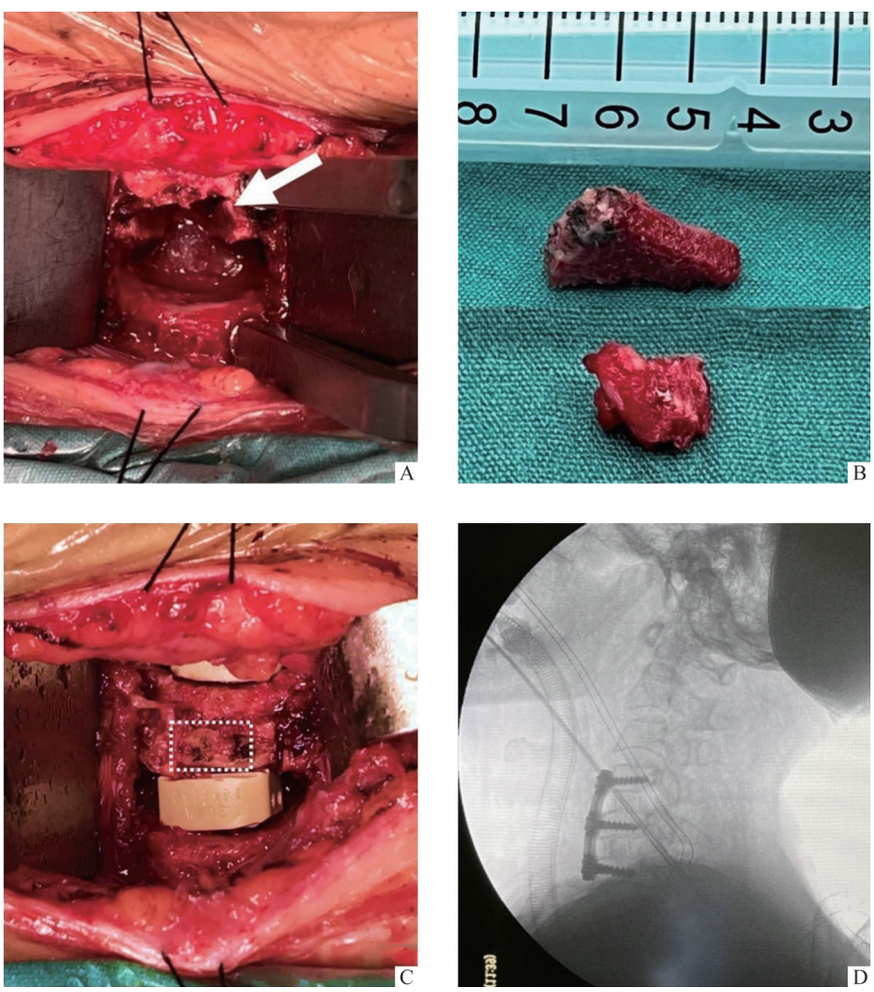


图1　ACMTF术中照片

Figure 1　Intraoperative photographs of the ACMTF procedure

A: Surgical field after V-shaped osteotomy (white arrow) and removal of the inferior intervertebral disc; B: Excised V-shaped bone block shown from multiple perspectives; C: In situ repositioning of the bone block and insertion of carbon-fiber cage following decompression; D: Intraoperative fluoroscopy confirming anterior plate-and-screw fixation. ACMTF: Anterior cervical mortise-tenon corpectomy and fusion.

1.4 术后管理

2组患者术后管理方案一致。术后常规放置引流管，引流量<25 mL/24 h时拔除。术后第1天鼓励患者佩戴颈托下床活动。颈托佩戴时间通常为3个月。术后常规应用抗生素预防感染(<24 h)，并使用神经营养药物及脱水剂减轻脊髓水肿。定期行下肢血管彩超筛查深静脉血栓。

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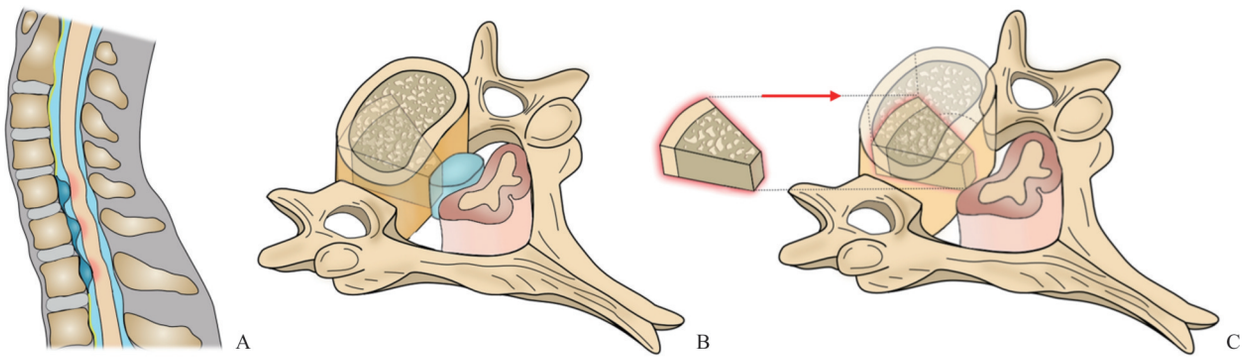


图2 ACMTF手术示意图

Figure 2 Schematic illustration of the ACMTF technique

A: Preoperative sagittal view showing segmental OPLL at C_5 to C_7; B: Three-dimensional schematic of target segment showing V-shaped osteotomy design; C: V-shaped osteotomy performed with ultrasonic bone scalpel, resection of the posterior longitudinal ligament and ossified lesion, and V-shaped bone block repositioned after decompression.

1.5 评价指标

1.5.1 临床疗效评价

分别于术前、术后3个月、6个月及12个月进行疗效评价。采用视觉模拟评分法(visual analogue scale，VAS)评估颈痛及上肢疼痛程度。采用JOA评分进行神经功能评价。神经功能改善率(improvement rate，IR)=(术后JOA评分−术前JOA评分)/(17−术前JOA评分)×100%。疗效判定分为优(≥75%)、良(50%~74%)、中(25%~49%)和差(<25%)。采用颈椎功能障碍指数(neck disability index，NDI)评估颈椎功能障碍对生活质量的影响。记录围手术期指标，包括手术时间、术中出血量及住院时间。

1.5.2 影像学评估

通过X线、CT三维重建及MRI进行测量。OR为轴位CT上骨化灶最大厚度与椎管前后径之比。脊髓有效空间(space available for the spinal cord，SAC)为正中矢状位CT/MRI上脊髓前方的剩余空间。颈椎前凸角(C_2~C_7 Cobb角)为C_2与C_7椎体下终板切线之间的夹角。植骨融合定义为：1)过伸过屈位X线片上棘突间距离变化<2 mm；2)CT显示骨小梁穿过移植物与终板界面连续生长；3)无内固定松动或透亮线[20]。沉降定义为末次随访时融合节段高度较术后即刻降低>3 mm[21]。

1.6 并发症记录

记录术中及术后并发症，包括脑脊液漏、硬膜撕裂、神经根损伤、椎动脉损伤、气管或食管损伤、吞咽困难、声音嘶哑、切口感染、血肿、再手术、螺钉松动/断裂、钛网移位等。

1.7 统计学处理

采用SPSS 26.0统计软件。计量资料以均数±标准差表示。组内术前、术后的比较采用配对t检验；组间比较采用独立样本t检验。计数资料(如性别、并发症发生率)以频数和率表示，采用χ^2检验或Fisher确切概率法(当理论频数<5时)。P<0.05为差异有统计学意义。

2 结 果

2.1 基线资料比较

ACMTF组和ACCF组患者在性别、年龄、病程长短、BMI、手术节段方面的差异均无统计学意义(均P>0.05，表1)，具有良好的可比性。

2.2 临床疗效评价

2组患者均顺利完成手术。术前及术后临床数据(表2)显示，ACMTF组患者的手术时间为(164.5±28.5) min，术中出血量为(385.9±63.5) mL；ACCF组患者的手术时间为(128.4±25.6) min，术中出血量为(352.4±68.7) mL；ACMTF组的手术时间显著长于ACCF组(P<0.001)，但2组术中出血量的差异无统计学意义(P>0.05)。末次随访时，2组患者神经功能及疼痛症状均显著改善。ACMTF组的JOA评分由术前9.1±1.6升至14.7±1.3(P<0.05)；IR为(67.2±9.6)%，其中优11例，良12例，中7例。ACCF组的JOA评分由术前的9.3±1.8升至14.5±1.5(P<0.05)；IR为(64.8±10.2)%，其中优10例，良11例，中9例。2组间JOA评分及IR的差异无统计学意义(均P>0.05)。ACMTF

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组的VAS评分由术前的5.1±1.5降至2.2±1.4(P<0.05)；NDI由(24.4±10.0)%降至(13.3±3.7)%(P<0.05)。ACCF组的VAS评分由术前的5.3±1.7降至2.4±1.6(P<0.05)；NDI由(25.1±10.5)%降至(14.0±4.2)%(P<0.05)。2组间同时间点的VAS评分和NDI的差异均无统计学意义(均P>0.05)。

表1　2组患者的基线资料比较

Table 1　Comparison of baseline data between the 2 groups

Items	ACMTF group (n=30)	ACCF group (n=30)	χ^2/t	P
Gender (Male/female)	18/12	20/10	0.287	0.592
Age/years	58.2±9.2	57.5±8.8	0.235	0.816
Symptom duration/months	26.4±12.3	28.1±14.5	0.385	0.703
BMI/(kg·m^{-2})	23.8±3.1	23.5±2.9	0.298	0.768
Surgical segment/[No.(%)]			0.533	0.970
C_3 to C_5	6(20.0)	6(20.0)		
C_3 to C_6	8(26.7)	7(23.3)		
C_4 to C_6	8(26.7)	7(23.3)		
C_4 to C_7	4(13.3)	6(20.0)		
C_5 to C_7	4(13.3)	4(13.4)		

Continuous data are expressed as mean±standard deviation. Categorical data are presented as frequencies or/and percentages. Gender and surgical segment are analyzed with χ^2 test. Age, symptom duration, and BMI are analyzed with the independent samples t-test. ACMTF: Anterior cervical mortise-tenon corpectomy and fusion; ACCF: Anterior cervical corpectomy and fusion; BMI: Body mass index.

表2　2组患者术前及术后临床数据

Table 2　Clinical pre- and post-operative data of the 2 groups

Items	ACMTF group (n=30)	ACCF group (n=30)	χ^2/t	P
Operative time/min	164.5±28.5	128.4±25.6	5.162	<0.001
Blood loss/mL	385.9±63.5	352.4±68.7	1.961	0.054
VAS scores				
Preoperative	5.1±1.5	5.3±1.7	−0.386	0.702
12-Month postoperative	2.2±1.4*	2.4±1.6*	−0.401	0.691
NDI/%				
Preoperative	24.4±10.0	25.1±10.5	−0.215	0.831
12-Month postoperative	13.3±3.7*	14.0±4.2*	−0.546	0.589
JOA scores				
Preoperative	9.1±1.6	9.3±1.8	−0.358	0.722
12-Month postoperative	14.7±1.3*	14.5±1.5*	0.432	0.669
IR/%	67.2±9.6	64.8±10.2	0.741	0.464
Complication/[No.(%)]				
C_5 nerve root palsy	0(0.0)	0(0.0)		1.000
Postoperative hematoma	0(0.0)	0(0.0)		1.000
CSF leakage	1(3.3)	1(3.3)		1.000
Implant complications	0(0.0)	6(20)		0.024

Continuous data are expressed as mean±standard deviation. Categorical data are presented as frequencies and percentages. The independent samples t-test is used for inter-group comparisons of operative time, blood loss, VAS scores, NDI, JOA scores, and IR. The paired t-test is used for intra-group comparisons of preoperative and postoperative VAS scores, NDI, and JOA scores. Complication is analyzed by χ^2 test. Compared with the preoperative data, *P<0.05. VAS: Visual Analogue Scale; NDI: Neck disability index; JOA: Japanese orthopaedic association; IR: Improvement rate; CSF: Cerebrospinal fluid.

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2.3 影像学检查结果

2组的术后OR均大幅下降，SAC显著增加(均P<0.05，表3)，证实了V形截骨窗口能够达到与次全切除相当的减压效果。ACMTF组术后颈椎前凸的角度恢复良好，且在随访期间维持稳定；ACCF组术后虽然也恢复了前凸的角度，但在随访期内(术后6个月及术后12个月)出现了矫正丢失现象，末次随访时(术后6个月及术后12个月)的前凸角度显著小于ACMTF组(均P<0.05)。

在融合率方面，ACMTF组术后3个月的融合率为60.0%，高于ACCF组的46.7%，但组间差异无统计学意义(P>0.05)，提示ACMTF可能有利于早期骨融合。在12个月时，ACMTF组实现了100%融合，证明了ACMTF的可靠性。沉降率是2组差异最显著的指标(P<0.05)，ACMTF组无1例发生严重沉降(>3 mm)；ACCF组中，有6例(20%)患者发生了严重沉降，部分病例伴有椎间高度丢失，表明随着时间推移，ACMTF在预防沉降方面表现出显著的优势。ACMTF组的代表性影像学图片如图3所示。

表3 2组患者的影像学检查结果

Table 3 Radiological results of the 2 groups

Items	ACMTF group (n=30)	ACCF group (n=30)	χ^2/t	P
OR/%				
Preoperative	43.3±5.1	44.1±5.3	−0.482	0.633
Postoperative	9.4±4.5*	11.2±4.8*	−1.202	0.238
12-Month postoperative	9.4±4.5*	11.2±4.8*	−1.202	0.238
SAC/mm				
Preoperative	5.5±2.5	5.3±2.7	0.236	0.815
Postoperative	13.8±2.0*	13.2±2.2*	0.862	0.394
12-Month postoperative	13.8±2.0*	13.2±2.2*	0.862	0.394
Cervical lordosis/(°)				
Preoperative	3.6±4.5	3.8±4.7	−0.134	0.894
Postoperative	19.7±2.1*	19.8±2.3*	−0.240	0.811
3-Month postoperative	18.8±2.3*	18.1±2.5*	1.104	0.274
6-Month postoperative	18.7±2.5*	17.0±2.7*	2.569	0.013
12-Month postoperative	18.4±2.6*	16.0±2.8*	2.705	0.001
Fusion rate/[No.(%)]				
3-Month postoperative	18(60.0)	14(46.7)	0.603	0.438
6-Month postoperative	26(86.7)	24(80.0)	0.120	0.729
12-Month postoperative	30(100.0)	28(93.3)		0.492
Severe subsidence/[No.(%)]				
3-Month postoperative	0(0.0)	0(0.0)		1.000
6-Month postoperative	0(0.0)	1(3.3)		1.000
12-Month postoperative	0(0.0)	6(20.0)		0.024

Continuous data are expressed as mean±standard deviation. Categorical data are presented as frequencies and percentages. The independent samples t-test is used for inter-group comparisons of OR, SAC, and cervical lordosis. The paired t-test was used for intra-group comparisons of OR, SAC, and cervical lordosis at different time points. The fusion rate and severe subsidence rate were analyzed using Fisher's exact test. Compared with the preoperative data, *P<0.05. OR: Occupation ratio; SAC: Space available for the spinal cord.

2.4 并发症情况

ACMTF组和ACCF组各有1例(3.3%)发生脑脊液漏，行腰大池引流及局部加压包扎处理，2组均于术后2周内拔管愈合。ACCF组中，有6例出现钛网的

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严重沉降，但因无明显症状，继续随访观察而未行翻修。2组均未出现硬膜撕裂、神经根损伤、椎动脉损伤、气管食管损伤、吞咽困难、声音嘶哑、切口感染、血肿、再手术、螺钉松动/断裂等并发症。

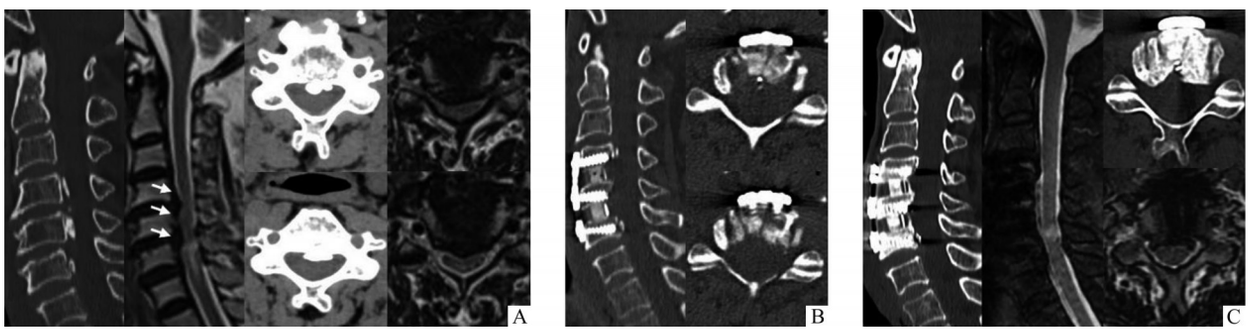


图3　ACMTF组的代表性病例的影像学图片(67岁女性)

Figure 3　Radiological images of a representative case of the ACMTF group (67-year-old woman)

A: Preoperative CT and MRI showing segmental OPLL at C_4 to C_6 with corresponding spinal cord compression and myelomalacia (white arrows). B: CT at 1 week postoperatively showing restored cervical lordosis, well-positioned internal fixation, and optimal placement of the V-shaped bone block. C: CT and MRI at 12 months postoperatively demonstrating solid fusion of the repositioned V-shaped bone block without subsidence, satisfactory decompression, and adequate dural SAC re-expansion.

3 讨　论

手术治疗OPLL的核心在于平衡减压的彻底性与脊柱的稳定性[1, 16]。传统的ACCF虽然在减压方面的评分较高，但在重建方面却屡遭诟病。钛网作为一种刚性圆柱体，与颈椎上下终板的接触仅限于边缘的几个点，这种点状接触导致了极高的应力集中。尤其在骨质疏松或多节段切除的病例中，钛网极易像活塞一样刺入椎体，导致高度丢失、沉降，进而引发颈椎后凸和神经再压迫。

ACMTF的设计本质上是一种结合生物力学稳定性与生物学重建理念的创新策略，其核心在于榫卯结构的应用。通过V形截骨获取的自体骨块与椎体缺损区形成几何嵌合，在前方钛板加压作用下可产生自锁效应，从而有效抵抗剪切力并避免移位。与传统ACCF中钛网的点状接触不同，ACMTF通过原位还纳实现面与面的骨性接触，显著增加受力面积，从根本上降低应力集中及移植物沉降风险。本研究中ACMTF组未发生严重沉降，而ACCF组沉降率达20%，进一步验证了其结构优势。此外，自体骨具有与宿主骨匹配的弹性模量，可避免应力遮挡效应，有利于应力传导及骨愈合，从而促进更牢固的骨性融合。上述力学与生物学优势共同构成了ACMTF优于传统重建方式的理论基础。

在神经功能改善方面，ACMTF组JOA评分从术前9.1分提高到术后14.7分，平均IR为67.2%，ACCF组从9.3分提高到14.5分，平均IR为64.8%，2组间无明显差异，与现有先进术式ACAF的IR相当[22-24]。此外，2组VAS评分和NDI显著下降，进一步证实了ACMTF在缓解疼痛和改善功能方面的疗效。影像学数据证实了减压的彻底性。ACMTF组术后的OR从43.3%降至9.4%，SAC从5.5 mm增至13.8 mm，与ACCF组的减压效果相似。这得益于超声骨刀的应用，其切骨而不伤软组织的特性，使得术者可以在V形深槽底部安全地进行操作，即使在视野相对狭窄的情况下，也能通过侧向摆动刀头和使用枪状咬骨钳，彻底清除侧后方的骨化灶。事实上，保留椎体侧壁不仅没有阻碍减压，反而保留了颈椎的部分前柱和侧柱支撑力，为术后即刻稳定性提供了额外保障。

在融合率方面，ACMTF组在术后12个月实现了100%的骨性融合，显著优于传统ACCF报道的融合率[10, 14, 25]。ACCF使用钛网填充碎骨，其愈合依赖于骨诱导和骨传导，且钛网内部的骨量往往有限，容易出现骨不连，而ACMTF还纳的是整块自体骨，作为1种结构性植骨材料，它通过爬行替代过程与周围骨质整合[26]。由于界面紧密贴合且无微动(得益于榫卯锁定)，骨小梁能快速穿越界面[15, 27]。此外，颈椎前凸的显著恢复凸显了ACMTF矫正矢状面力线的能力，这对于减轻长期轴性疼痛和邻近节段退变至关

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重要。术后6个月和12个月，ACMTF组C_2~C_7的Cobb角大于ACCF组，显示其在维持生理曲度方面的优势[25]。脑脊液漏是OPLL前路手术最常见的并发症，尤其是在骨化灶与硬膜粘连紧密的情况下。本研究中2组脑脊液漏发生率均为3.3%，说明ACMTF并未因操作空间的限制而增加硬膜损伤的风险。同时，由于V形骨块移除后可以直接显露骨化灶的基底，术者可以从侧方安全平面开始分离，这在一定程度上可能比ACCF直接处理凸起的骨化灶更安全。

与ACDF相比，ACMTF具有更大的前路减压操作空间，更适用于累及椎体后壁或节段稍长的节段型OPLL[14]。与ACAF相比，ACMTF通过直接切除骨化病灶实现充分减压，避免了病变残留，可能降低了骨化继续进展导致复发的风险[28-29]，但其适应范围相对较窄，主要适用于压迫较轻、基底不宽的节段型OPLL。而对于更为严重、基底宽大的病例，ACAF可能更具优势。此外，ACAF技术要求高，通常需依赖导航或特殊器械，而ACMTF不依赖上述设备，操作也相对简单，更适于基层医院开展。此外，近期有研究[30]报道了颈前路X型截骨减压植骨融合术(anterior cervical X-shape-corpectomy and fusion，ACXF)。虽然ACXF也是对椎体进行截骨并还纳部分截骨块，但ACXF截骨涉及整个椎体高度，且仅还纳前半部分截骨骨块，相对容易发生塌陷，同时对前凸的矫正效果有限[30-31]。ACMTF采用局部V型截骨并将骨块整体还纳，形成稳定的榫卯结构，既保留了脊柱环形骨性结构，又有助于增强重建稳定性和维持颈椎前凸。对于混合型或连续型OPLL，后路手术仍是重要选择，但在节段型病变中疗效相对欠佳[28]。后路手术主要依赖脊髓后漂，在节段型病变，尤其椎管狭窄或骨化物突出较明显时往往存在局限，并可能带来C_5神经麻痹、慢性颈痛及活动受限等问题[18-19, 32-33]。相比之下，ACMTF可在有限暴露下实现直接减压，并兼顾结构稳定性与生物学重建[34-35]。

因此，ACMTF提供了一种损伤更小、结构更稳固的替代方案。但必须指出，ACMTF是一项技术要求更高的手术。ACMTF组的平均手术时间比ACCF组长约36 min。主要原因包括V形截骨需要精确的角度控制和超声骨刀操作的技术要求较高；榫头的修整和还纳需要反复试位。本组病例包含了手术学习曲线早期病例，随着术者经验积累，手术时间有望缩短。本团队最近10例ACMTF的平均手术时间已降至135 min左右。另外，本研究存在样本量较小、随访时间较短及回顾性设计的局限，对于邻近节段退变等远期并发症的评估尚显不足。未来需要更大样本量的多中心随机对照试验及5年以上的长期随访来进一步验证ACMTF的远期疗效。

综上，ACMTF体现了脊柱外科从机械重建向生物重建转变的理念。与传统的ACCF相比，ACMTF在保证同等神经减压效果的前提下，通过自体骨的还纳重建和独特榫卯力学结构，提高了植骨融合率，降低了钛网沉降的风险，并能更持久地维持颈椎的生理曲度。结构稳定性和生物学优势使其成为不伴严重硬膜粘连的节段型OPLL的优选治疗方案。

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