临床论著

颈椎前路 Hybrid 术式治疗相邻双节段颈椎病的中长期疗效分析

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【摘要】目的:观察颈椎前路 Hybrid 术式治疗相邻双节段颈椎病的中长期临床疗效、影像结果及 Bryan 人工颈椎间盘置换节段的在体运动功能状态。**方法**:回顾性分析 2010 年 7 月~2013 年 12 月于我院行颈椎前路相邻双节段 Hybrid 手术的患者,置换节段采用 Bryan 人工颈椎间盘,融合节段采用 MC+椎间融合器,纳入末次随访时置换节段活动度(range of motion,ROM)>5°的 43 例患者,其中男性 23 例、女性 20 例,年龄 49.1±5.6 岁。脊髓型颈椎病 26 例,神经根型颈椎病 6 例,混合型颈椎病 11 例。术后随访 84~119 个月(95.43±8.21 个月),采用日本骨科协会(Japanese Orthopaedic Association,JOA)颈椎评分、颈椎功能障碍指数(neck disability index,NDI)、疼痛视觉模拟评分(visual analogue scale,VAS)及 Odom 分级评估临床疗效。收集术前与末次随访时的颈椎中立侧位和动力位 X 线片,对比术前与末次随访时的颈椎整体 ROM 及曲度(C2-C7)、手术节段曲度、置换节段屈伸旋转中心(flexion and extension-center of rotation,FE-COR)及 ROM、手术相邻节段 ROM;末次随访时,观察邻近节段退变(adjacent segment degeneration,ASD)发生情况、融合节段融合情况,测量置换节段平移距离与关节突关节解剖参数:上关节突高度(height of superior articular process,HSAP)、关节突关节间隙倾斜度(orientation of zygapophyseal joint spaces,OZJS)和上关节突关节面长度(length of superior articular surface,LSAS),分析置换节段 FE-COR 与各项随访指标的相关性。**结果**:末次随访时,JOA 评分较术前显著性升高(9.26±3.38 vs 15.21±1.42,*P*<0.05),改善率为(80.23±13.80)%,NDI、颈痛 VAS 评分及双上肢痛 VAS 评分均较术前显著性降低(34.12±8.96 vs 7.21±4.32,*P*<0.05;5.77±2.28 vs 1.72±0.96,*P*<0.05;5.26±2.67 vs 1.14±0.83,*P*<0.05),改善率分别为(80.03±10.52)%、(69.85±13.44)%和(78.84±15.89)%。Odom 分级优 24 例、良 12 例、可 7 例,优良率为 83.72%。颈椎整体曲度、手术节段曲度分别由术前的 14.76°±8.04°、4.78°±5.86°增加至末次随访的 20.62°±9.06°、6.75°±4.65°(*P*<0.05),颈椎整体 ROM、置换节段 FE-COR 及 ROM、手术相邻节段 ROM 与术前比较均无统计学差异(*P*>0.05)。81 个纳入研究的手术相邻节段(上位 43 个、下位 38 个)7 个节段发生 ASD(8.64%),分属于 7 例患者(7/43,16.28%),1 例患者融合节段未获得骨性融合,但处于稳定状态(ROM<2°),其余患者融合节段均获得骨性融合,未发现与 FE-COR 横坐标(X)相关的随访指标(|*r*|<0.5 或 *P*>0.05),FE-COR 纵坐标(Y)与同节段 ROM、平移距离呈负相关(*r*=-0.674,*P*<0.05;*r*=-0.792,*P*<0.05),与 HSAP 呈正相关(*r*=0.754,*P*<0.05),与其他随访指标无显著相关性(|*r*|<0.5 或 *P*>0.05)。**结论**:颈椎前路相邻双节段 Hybrid 手术患者 7年以上随访的临床与影像学结果满意,无证据显示融合节段对置换节段运动功能状态产生明显影响。

【关键词】颈椎病;颈椎前路 Hybrid 手术;Bryan 人工颈椎间盘;关节突关节;旋转中心;邻近节段退变
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Analysis of mid- to long-term follow-up outcomes after anterior cervical Hybrid surgery for the treatment of adjacent two-level cervical spondylosis/LI Chuanhong, YU Xing, XIONG Yang, et al//Chinese Journal of Spine and Spinal Cord, 2022, 32(7): 595-604

【Abstract】Objectives: To observe the clinical and radiological outcomes of mid- to long-term follow-up of anterior cervical Hybrid surgery for the treatment of adjacent two-level cervical spondylosis, and to evaluate the in vivo motor function status of the arthroplasty level with Bryan artificial cervical disc. **Methods:** A retrospective study was performed on the patients who underwent adjacent two-level anterior cervical Hybrid

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surgery (Bryan disc for arthroplasty level and MC+cage for fusion level) from July 2010 to December 2013. And a total of 43 patients (23 males and 20 females) each with a range of motion (ROM) >5° at the arthroplasty segment at final follow-up were included, who were averaged 49.1±5.6 years old at the time of surgery. Preoperative symptoms were mainly attributable to myelopathy(26 cases), radiculopathy(6 cases), and myeloradiculopathy(11 cases). The mean follow-up period was 95.43±8.21 months(range, 84-119 months). The clinical outcomes were assessed by the Odom criteria, Japanese Orthopaedic Association(JOA) score, visual analogue scale (VAS), and neck disability index (NDI). The neutral-lateral and flexion-extension cervical radiographs were collected before operation and at final follow-up. The radiological parameters including the ROMs of the overall cervical spine(C2-C7) and the arthroplasty level, flexion and extension-center of rotation (FE-COR) at the arthroplasty level, ROM of adjacent levels, as well as the lordosis angles of the operated level and overall cervical spine (C2-C7) were measured and compared between preoperation and the final follow-up. At final follow-up, adjacent segment degeneration(ASD) and bony fusion at the fusion level were observed, and the translation and the anatomical parameters of zygapophyseal joints were measured at the arthroplasty level, including the height of superior articular process(HSAP), orientation of zygapophyseal joint spaces(OZJS), and the length of superior articular surface(LSAS), and meanwhile correlations between FE-COR and other follow-up data were analyzed. **Results:** In comparison with preoperative values, the JOA score significantly increased(9.26±3.38 vs 15.21±1.42, P<0.05) with an improvement rate of (80.23±13.80)%, and the NDI, VAS(neck pain), and VAS(arm pain) significantly decreased(34.12±8.96 vs 7.21±4.32, P<0.05; 5.77±2.28 vs 1.72±0.96, P<0.05; 5.26±2.67 vs 1.14±0.83, P<0.05) with improvement rates of (80.03±10.52)%, (69.85±13.44)%, and (78.84±15.89)%, respectively. The excellent or good rate in Odom criteria was 83.72%(excellent, 24 cases; good, 12 cases; satisfactory, 7 cases). The lordosis angles of overall cervical spine and the operated level increased significantly from 14.76°±8.04° and 4.78°±5.86° preoperatively to 20.62°±9.06° and 6.75°±4.65° at final follow-up, respectively(P<0.05). ROM of the overall cervical spine, FE-COR and ROM at the arthroplasty level, and ROM of adjacent levels at final follow-up showed no significant changes from those before operation(P>0.05). A total of 81 adjacent levels(43 superior levels and 38 inferior levels) were included in the study, and ASD occurred in 7 adjacent levels(7/81, 8.64%) of 7 patients(7/43, 16.28%). At final follow-up, one patient failed to achieve bony fusion at the fusion level, but the state was stable (ROM<2°). The fusion levels of the other patients all met the criteria for bony fusion. At final follow-up, no follow-up data showed at least moderate correlation with abscissa(X) of FE-COR at the arthroplasty level(P>0.05 or $|r|$<0.5), and ordinate(Y) of FE-COR was negatively correlated with ROM and translation(r=-0.674, P<0.05; r=-0.792, P<0.05) but positively correlated with HSAP(r=0.754, P<0.05) at the arthroplasty level, and moreover, no correlation was found between ordinate (Y) of FE-COR at the arthroplasty level and any other parameters (P>0.05 or $|r|$<0.5). **Conclusions:** The clinical and radiological outcomes were satisfactory at least 7 years after the adjacent two-level anterior cervical Hybrid surgery, and there was no evidence that the fusion level had an effect on the motor function status of the arthroplasty level.

【Key words】 Cervical spondylosis; Anterior cervical Hybrid surgery; Bryan artificial cervical disc; Zygapophyseal joints; Center of rotation; Adjacent segment degeneration

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人工颈椎间盘置换术(artificial cervical disc replacement,ACDR)在神经减压的同时保留了手术节段运动功能。已有研究报道其中长期随访临床疗效与颈椎前路椎间盘切除融合术(anterior cervical discectomy and fusion,ACDF)一致,并在一定程度上具有延缓邻近节段退变(adjacent segment degeneration,ASD)的作用[1-3]。采用 ACDR 与 ACDF 相结合的 Hybrid 术式治疗相邻双节段症状性颈椎间盘退行性疾病 (cervical degenerative disc disease, CDDD)可同时兼顾颈椎稳定性与运动功能[4,5],通常在无巨大骨赘生成、椎间高度与活动度(range of motion,ROM)无明显丢失的责任节段应用 ACDR, 而在退变较重的责任节段施行 ACDF。已有学者关注颈椎前路相邻双节

段 Hybrid 手术与单纯 ACDR 或 ACDF 相比,临床疗效、影像结果、颈椎生物力学环境是否不同,ASD、异位骨化(heterotopic ossification,HO)等并发症发生率有无差异[6,7],但对该术式中长期随访置换节段的 ROM,融合节段是否影响邻近人工椎间盘的运动质量缺乏系统的研究报道[8]。本研究拟对接受颈椎前路相邻双节段 Hybrid 手术的患者进行 7 年以上的随访,采用屈伸旋转中心(flexion and extension-center of rotation,FE-COR)评价置换节段的运动功能状态,分析在中长期随访中置换节段运动功能状态的变化,并评估 Hybrid 术式中与置换节段 FE-COR 位置相关的因素。

1 资料与方法

1.1 一般资料

回顾性分析 2010 年 7 月~2013 年 12 月于我院行颈椎前路相邻双节段 Hybrid 手术的患者,ACDR 采用 Bryan 人工颈椎间盘,ACDF 采用 MC+椎间融合器。病例纳入标准:(1)年龄 30~60 岁;(2)符合相邻双节段症状性 CDDD 诊断标准,保守治疗 6 周以上无效;(3)施行 ACDR 的节段致压物为突出椎间盘等软性组织,无椎体前后缘巨大骨赘、严重后凸畸形与节段性不稳,椎间高度和 ROM 大部分保留[9,10];(4)同一手术团队施术;(5)随访时间≥84 个月。排除标准:(1)伴先天性颈椎管狭窄,黄韧带、后纵韧带骨化,严重的颈椎骨折、脱位或畸形;(2)颈椎肿瘤、感染性疾病;(3)术前或随访期间接受其他颈椎手术。本研究获得我院医学伦理委员会批准(批准号:2021DZMEC-082-02),临床研究前所有患者都签署了知情同意书。

1.2 临床疗效评估

采用日本骨科协会(Japanese Orthopaedic Association,JOA)颈椎评分、颈椎功能障碍指数(neck disability index,NDI)、疼痛视觉模拟评分(visual analogue scale,VAS)、Odom 分级评估临床疗效。JOA 评分改善率=(术后 JOA 评分-术前 JOA 评分)/(17-术前 JOA 评分)×100%;NDI、VAS 评分改善率=(术前总分-术后总分)/术前总分×100%。Odom 分级:优,术前症状完全消失,日常工作不受限;良,术前症状偶尔出现,日常工作无明显受限;可,术前症状有改善,日常活动明显受限;差,病情无改善甚至加剧。

1.3 影像学评估

收集患者术前及末次随访时的颈椎中立侧位、动力位(前屈后伸)X 线片,由两名骨科医师通过 Mimics 17.0(Materialise,比利时)和 ImageJ(Wayne Rasband,美国国立卫生研究院)图像管理软件独立测量影像结果,每个指标测量 3 次,结果取均值。

用 Cobb 角法测量颈椎整体曲度(中立侧位 C2-C7 Cobb 角)、手术节段曲度(中立侧位手术节段 Cobb 角)、颈椎整体 ROM(C2-C7 Cobb 角屈伸变化)、置换节段与手术上下位相邻节段 ROM(superior-segment range of motion,SROM;inferior-segment range of motion,IROM)(目标节段椎间角屈伸变化),Cobb 角开口向前为正值,反之为负;在颈椎后伸位 X 线片上测量关节突关节的解剖参数(颈椎后伸位片有利于显示关节突关节边缘)[11,12],包括:上关节突高度(height of superior articular process,HSAP)、关节突关节间隙倾斜度(orientation of zygapophyseal joint spaces,OZJS)、上关节突关节面长度(length of superior articular surface,LSAS);参考 Amevo 等[13]的方法测量椎体高度和宽度(图 1)。为消除个体间椎体大小差异带来的统计学误差,增加数据的可比性,将 HSAP、LSAS 分别归一化为占椎体高度、宽度的百分比[14,15],即 HSAP=(HSAP 测量值/椎体高度)×100%,LSAS=(LSAS 测量值/椎体宽度)×100%。采用中垂线法测量置换节段 FE-COR,应用 Mimics 17.0 软件自动配准叠加颈椎动力位 X 线片中置换节段下位椎体,分别连接两个上位椎体上选取的 3 组对应标志点,连线中垂线相交于 FE-COR[16,17],同时在叠加的动力位 X 线片上测量 Bryan 人工椎间盘上终板前下角在下终板平行线方向上移动的距离,即置换节段平移距离[14,18],同前将平移距离归一化为占椎体宽度的百分比,即平移距离=(平移距离测量值/椎体宽度)×100%(图 2)。

依据 Walraevens 等[19]的方法在中立侧位 X 线片上对手术相邻节段椎间盘退变程度进行评分,包括椎间高度、椎体前缘骨赘、终板硬化,无退变(0 分),轻度退变(1~3 分),中度退变(4~6 分),重度退变(7~9 分)。末次随访时评分较术前增加即认为有 ASD 发生。ACDF 节段获得骨性融合的

标准[20]为:有连续性骨桥通过椎间隙连接相邻上下终板,且动力位 X 线片显示融合节段棘突间距离屈伸变化<2mm 或 ROM<2°。

1.4 统计学分析

应用 SPSS 20.0 软件进行统计学分析,测量结果以均数±标准差($\bar{x}\pm s$)表示。数据呈正态分布参数术前与末次随访的比较采用配对 t 检验,非正态分布参数采用 Wilcoxon 检验。相关性检验采用 Pearson 相关系数(数据呈正态分布)与 Spearman 相关系数(数据非正态分布),r 值绝对值($|r|$)≥0.5 表明至少有中度的相关性[14]。P<0.05 为差异有统计学意义。

2 结果

共有 47 例颈前路相邻双节段 Hybird 手术的患者获得随访,其中 4 例末次随访时因Ⅲ~Ⅳ度 HO,置换节段 ROM<5°而排除(测量 FE-COR 时将产生较大误差)[21],最终 43 例患者纳入本研究。男性 23 例,女性 20 例;年龄 37~58 岁(49.1±5.6 岁)。脊髓型颈椎病 26 例,神经根型颈椎病 6 例,混合型颈椎病 11 例。手术节段及方式:C3/4 ACDF +C4/5 ACDR 6 例,C4/5 ACDF +C5/6 ACDR 5 例,C4/5 ACDR+C5/6 ACDF 12 例,C5/6 ACDF +C6/7 ACDR 6 例,C5/6 ACDR +C6/7 ACDF 14 例。随访 84~119 个月(95.43±8.21 个月)。

2.1 临床疗效

末次随访时,患者由症状性 CDDD 引起的感觉、运动及括约肌功能障碍明显改善,颈肩、双上肢疼痛明显缓解,JOA 评分较术前显著性升高(P<0.05),改善率为(80.23±13.80)%,NDI、颈痛及双上肢痛 VAS 评分较术前显著性降低(P<0.05),改善率分别为(80.03±10.52)%、(69.85±13.44)%和(78.84±15.89)%(表 1)。末次随访时 Odom 分级优 24 例,良 12 例,可 7 例,优良率为 83.72%。

2.2 影像学资料

术前和末次随访时的影像学测量结果见表 2。末次随访时,颈椎整体 ROM、置换节段 ROM 得到良好保留,与术前相比均无统计学差异(P>0.05),未出现手术相邻节段过度活动,SROM、IROM 较术前无明显变化(P>0.05),与术前相比颈椎生理性前凸有所恢复,颈椎整体曲度、手术节段曲度较术前均有所增加(P<0.05),置换节段 FE-COR 位置得到维持,FE-COR-X、FE-COR-Y

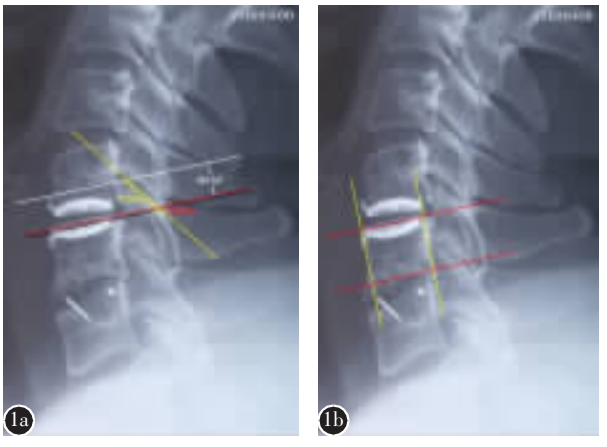

图 1 后伸位测量置换节段关节突关节解剖参数 **a** 作置换节段下位椎体上终板和上关节突关节面的切线(红线与黄线),分别过置换节段下位椎体上关节突最高点、置换节段上位椎体下关节突最低点作红线的平行线(白线与黑线),红线与白线间的垂直距离为上关节突高度(HSAP),红线与黄线间的夹角为关节突关节间隙倾斜度(OZJS),黄线与白线、黑线的交点间的距离为上关节突关节面长度(LSAS) **b** 参考 Amevo 等[13]的方法,作置换节段下位椎体四周的切线(红线与黄线互相垂直),两红线(互相平行)、两黄线(互相平行)间的垂直距离分别为椎体的高度、宽度

Figure 1 Measurements of the anatomical parameters of the zygapophyseal joints at the arthroplasty level on the extension radiograph **a** The tangents of the superior endplate and superior articular surface of the inferior vertebra(C6) at the arthroplasty level (in red and yellow) were drawn first, and two additional lines parallel to the red line were then made, one touching the highest point of the superior articular process of C6 vertebra(in white), and the other touching the lowest point of the inferior articular process of the superior C5 vertebra(in black). The vertical distance between the red and white lines was the measured height of superior articular process(HSAP), the angle between the red and yellow lines was the orientation of zygapophyseal joint spaces(OZJS), and the distance between the two intersections(yellow and white lines; yellow and black lines) was the measured length of superior articular surface(LSAS) **b** Referring to the method of Amevo et al[13], the tangents(red lines and yellow lines were perpendicular to each other) around C6 vertebra were drawn, and the vertical distances between the two red lines(parallel to each other) and the two yellow lines(parallel to each other) corresponded to the height and width of the vertebral body, respectively

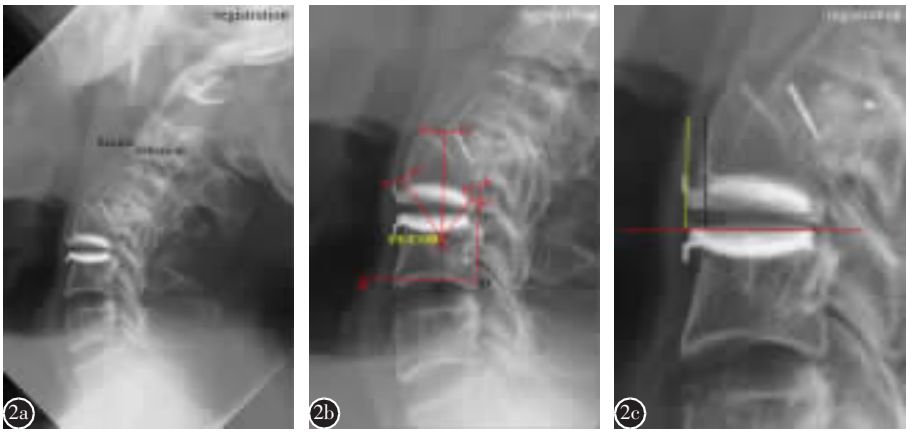

图 2　置换节段屈伸旋转中心（FE-COR）及平移距离测量　**a** 应用 Mimics 17.0 软件的自动配准功能重叠颈椎动力位片中置换节段下位椎体（C5）　**b** 在前屈位置换节段上位椎体(C4)上标记 3 个解剖标志点 P1、P2、P3，在后伸位 C4 椎体上标记对应的标志点 P1′、P2′、P3′，连接 P1 与 P1′、P2 与 P2′、P3 与 P3′三条连线的中垂线相交于一点，即 FE-COR。建立直角坐标系描述 FE-COR 的位置，参考 Amevo 等[13]的方法，互相垂直的 C5 椎体下终板、后缘切线分别为 X、Y 轴，X、Y 轴交于原点 O，向左、向上分别为 X、Y 轴的正方向。根据图 1 的方法得出 C5 椎体的宽度和高度(OX1 与 OY1)，FE-COR 在 X、Y 轴上的投影点分别为 X2、Y2。FE-COR 横坐标：FE-COR-X=(OX2/OX1)×100%，FE-COR 纵坐标：FE-COR-Y=(OY2/OY1)×100%　**c** 在通过对齐 C5 叠加的动力位片中，分别在屈、伸位过 Bryan 间盘上终板前下角作下终板切线(红线)的垂线黄线与黑线，黄线与黑线间的垂直距离即平移距离

Figure 2　Measurements of the flexion and extension-center of rotation(FE-COR) and translation at the arthroplasty level　**a** Superimposing the two inferior vertebrae (C5) at the arthroplasty levels in the flexion-extension radiographs using the automatic registration of Mimics 17.0 software　**b** In the superior vertebra(C4) of the arthroplasty level, three anatomical landmarks P1, P2, and P3 in the flexion radiograph and their corresponding P1′, P2′, and P3′ in the extension radiograph were located and labeled. Straight lines connecting P1 and P1′, P2 and P2′, as well as P3 and P3′, and the perpendicular bisectors of the three connecting lines intersected at one point, i.e., FE-COR. A rectangular coordinate system was established to describe the location of FE-COR according to the method of Amevo et al [13]. The X-and Y-axis were defined as the mutually perpendicular tangents of the inferior endplate and posterior edge of C5 vertebral body (the origin was point O), and the forward and upward directions were taken as the positive directions of X-and Y-axis, respectively. Simultaneously, the width and height of C5 vertebral body (OX1 and OY1) were measured according to the procedures in Figure 1. The FE-COR was vertically projected onto points X2 and Y2 on the X-and Y-axis, respectively, and the location of FE-COR was noted as the following, abscissa: FE-COR-X=(OX2/OX1)×100%, ordinate: FE-COR-Y=(OY2/OY1)×100%　**c** In the flexion-extension radiographs superimposed by aligning C5 vertebra, two lines perpendicular to the tangent of the inferior endplate of the Bryan disc (in red) were drawn, which touched the vertex at the antero-inferior corner of the superior endplate of the Bryan disc in flexion (in yellow) and extension (in black). The vertical distance between the yellow and black lines was the translation measured value

与术前比较无统计学差异(P>0.05)。

末次随访时，1 例患者融合节段未获得骨性融合，椎间隙可见透亮影，无连续性骨桥形成，但处于稳定状态(ROM<2°)，其余患者融合节段均获得骨性融合。81 个手术相邻节段(上位 43 个，下位 38 个)术前和末次随访时 X 线片显影清晰，纳入研究，其中 7 个节段发生 ASD(7/81，8.64%)，分属于 7 例患者（7/43，16.28%），C4-C5 3 例、C6-C7 3 例、C7-T1 1 例。3 例为上位相邻节段 ASD(3/43，6.98%)，皆与置换节段相邻；4 例为下位相邻节段 ASD(4/38，10.53%)，其中 3 例与融合节段相邻，1 例与置换节段相邻。末次随访时 4 例

表 1　术前和末次随访临床评分的比较（$\bar{x}\pm s$，n=43）

Table 1　Comparison of clinical scores between preoperation and final follow-up

	术前 Preoperation	末次随访 Final follow-up	Z 值 Z value	P值 P value
JOA评分(分) JOA score	9.26±3.38	15.21±1.42①	-5.725	<0.001
颈痛 VAS 评分(分) VAS score(neck pain)	5.77±2.28	1.72±0.96①	-5.732	<0.001
上肢痛 VAS 评分(分) VAS score(arm pain)	5.26±2.67	1.14±0.83①	-5.593	<0.001
NDI(分)	34.12±8.96	7.21±4.32①	-5.714	<0.001

注：①与术前相比 P<0.05

Note: ①Compared with preoperation, P<0.05

退变评分较术前进展,但分级无变化(3 例轻度退变,1 例中度退变),3 例分级增加 (1 例无退变转为轻度退变,2 例轻度退变转为中度退变)。

2.3 FE-COR 与其他随访指标的相关性

末次随访时,置换节段 FE-COR 与其他随访指标的相关性见表 3。FE-COR-Y 与同节段 HSAP 呈正相关而与同节段平移距离、ROM 呈负相关($|r|\geq0.5$,$P<0.05$),与临床疗效及其他影像结果无中度及以上相关性($|r|<0.5$ 或 $P>0.05$),未发现与 FE-COR-X 中度以上相关的随访指标 ($|r|<0.5$ 或 $P>0.05$)。置换节段平移距离与同节段 HSAP 呈负相关 ($r=-0.760$,$P<0.001$),与 OZJS、LSAS 无明显相关性($P>0.05$);置换节段 ROM 与同节段平移距离呈正相关 ($r=0.747$,$P<0.001$),与 HSAP 呈负相关 ($r=-0.605$,$P<0.001$),与 OZJS、LSAS 无显著相关性($P>0.05$)。

3 讨论

颈椎前路相邻双节段 Hybrid 手术已在临床应用 10 余年[4,5]。既往研究认为该术式通过人工椎间盘的植入避免了手术相邻节段 ROM 与力学负荷的过度增加[22],从而预防 ASD 的发生,在保证满意临床疗效的同时较相邻双节段 ACDF 有明显的生物力学与运动学优势。本组病例经过至少 7 年的随访,各项临床疗效评分均较术前明显改善,肯定了该术式的中远期疗效。同时影像学测量发现,颈椎生理性前凸得以部分恢复,颈椎整体 ROM 与置换节段 ROM 得以保留,手术相邻节段未出现过度活动,ASD 的发生率低于既往报道中相邻双节段 ACDF 经 2~5 年随访的发生率(均在 X 线片上采用相似评估方法)[23~26]。充分表明 Hybrid 术式减少了对颈椎整体及手术局部生物力学环境的干扰,理论上有助于延缓手术相邻节段的退变,并可能是本研究临床疗效得以长期维持的原因之一。

然而,人工椎间盘设计的初衷是在正常生物力学环境下模拟生理运动,Hybrid 术式中的融合节段可能会影响置换节段的生物力学环境,导致置换节段的应力增加或过度活动[8],这些运动学和生物力学的异常最终可能引起人工椎间盘的寿命降低甚至手术失败。本研究中末次随访时发现置换节段的 ROM 得以保留,且与术前无显著性差异,但这并不能说明置换节段的运动质量未受融合节段的干扰。FE-COR 是 ACDR 在体运动学研究中常用的运动质量参数[27],可有效反映椎间运动模式,在目标节段 ROM 正常时发现其运动模式的异常[28,29]。有研究发现,FE-COR 还与目标节段生物力学环境密切相关,异常的 FE-COR 会在正常范围的屈伸运动过程中于关节突关节、椎间盘/假体内、骨-假体界面等处产生非生理的或过度的力学负荷[30~32]。本研究结果显示,置换节段 FE-COR 在末次随访时得到良好的维持,说明置

表 2 术前和末次随访影像结果的比较 ($\bar{x}\pm s$)

Table 2 Comparison of radiological outcomes between preoperation and final follow-up

	n	术前 Preoperation	末次随访 Final follow-up	*t*值/*Z* 值 *t* value/*Z* value	*P*值 *P* value
颈椎整体 ROM(°) Overall cervical ROM	43	41.72±10.92	43.03±11.20	$t=-0.709$	0.484
颈椎整体曲度(°) Overall cervical lordosis angle	43	14.76±8.04	20.62±9.06	$t=-3.297$	0.003
手术节段曲度(°) Lordosis angle (operated levels)	43	4.78±5.86	6.75±4.65	$t=-2.441$	0.021
置换节段 ROM(°) ROM (arthroplasty level)	43	9.49±3.35	10.09±3.01	$t=-0.808$	0.425
上位相邻节段(°) ROM SROM	43	10.89±4.52	11.14±4.11	$t=-0.465$	0.645
下位相邻节段(°) ROM IROM	38	6.53±3.44	7.16±4.10	$Z=-1.039$	0.299
屈伸旋转中心横坐标(%) FE-COR-X	43	36.59±18.76	41.69±19.02	$Z=-0.980$	0.327
屈伸旋转中心纵坐标(%) FE-COR-Y	43	71.88±15.09	74.90±20.77	$t=-0.955$	0.347

注:5 例患者术前和/或末次随访手术下位相邻节段 X 线片显影欠佳,测量 IROM 困难,未纳入 IROM 对比研究

Notes: Five cases were excluded from the IROM comparative analysis because the inferior adjacent levels were not clearly visible in the preoperative and/or final follow-up radiographs, causing difficulty in measuring IROM

换节段的运动质量与生物力学环境在长期的随访中保持在与术前相似的稳定状态，未受融合节段的明显影响。此外，置换节段运动质量的维持有助于改善手术相邻节段甚至颈椎整体的运动学及生物力学环境，被认为是减缓 ASD 发生、维持中长期临床疗效的深层次运动学原因[33,34]。但是 ASD 是自然退变的结果还是融合术所致，亦或者是两种因素共同引起，目前尚无定论[35,36]。本研究中 7 个出现 ASD 的节段中 6 个术前即存在椎间盘退变，表明已明显存在的椎间盘自然退变进程可能在 ASD 的产生中发挥一定的作用[37]，而 Hybrid 术式较单纯的融合手术理论上减轻了对手术相邻节段自然退变进程的加速。

本研究通过相关性分析进一步探索与置换节段 FE-COR 相关的因素，结果表明末次随访置换节段 FE-COR-Y 与同节段 HSAP 呈正相关，而与

表 3 末次随访置换节段 FE-COR 与其他随访指标的相关性分析

Table 3 Correlations between FE-COR and other follow-up data at final follow-up

	n	屈伸旋转中心横坐标 FE-COR-X(%)		屈伸旋转中心纵坐标 FE-COR-Y(%)	
		*r*值 *r* value	*P*值 *P* value	*r*值 *r* value	*P*值 *P* value
年龄(岁) Age	43	0.131	0.407	-0.134	0.399
随访时间(月) Follow-up period	43	0.088	0.581	0.189	0.23
JOA评分(分) JOA score	43	-0.093	0.618	-0.054	0.773
颈痛 VAS 评分(分) VAS score(neck pain)	43	0.062	0.742	-0.335	0.066
上肢痛 VAS 评分(分) VAS score(arm pain)	43	0.019	0.92	-0.032	0.863
NDI评分(分) NDI score	43	-0.029	0.876	0.079	0.674
JOA评分改善率(%) JOA improvement rate	43	0.009	0.962	0.162	0.383
颈痛 VAS 评分改善率(%) VAS(neck pain) improvement rate	43	-0.033	0.861	0.438	0.014
上肢痛 VAS 评分改善率(%) VAS(arm pain) improvement rate	43	0.057	0.761	0.133	0.475
NDI评分改善率(%) NDI improvement rate	43	0.048	0.797	-0.063	0.737
颈椎整体 ROM(°) Overall cervical ROM	43	-0.019	0.92	0.085	0.651
颈椎整体曲度(°) Overall cervical lordosis angle	43	0.001	0.995	0.057	0.761
手术节段曲度(°) Lordosis angle(operated levels)	43	0.247	0.18	0.214	0.247
置换节段 ROM(°) ROM(arthroplasty level)	43	-0.173	0.352	-0.674#	<0.001
上位相邻节段 ROM(°) SROM	43	-0.011	0.952	0.055	0.77
下位相邻节段 ROM(°) IROM	39	0.137	0.463	-0.016	0.933
置换节段平移距离(%) Translation(arthroplasty level)	43	0.107	0.565	-0.792#	<0.001
置换节段 HSAP(%) HSAP(arthroplasty level)	43	-0.360	0.019	0.754#	<0.001
置换节段 OZJS(°) OZJS(arthroplasty level)	43	-0.077	0.629	-0.153	0.332
置换节段 LSAS(%) LSAS(arthroplasty level)	43	-0.212	0.178	-0.095	0.551

注：4 例患者末次随访手术下位相邻节段 X 线片显影欠佳，测量 IROM 困难，未纳入相关性研究

Notes: Four cases were excluded from the correlation analysis, because the inferior adjacent levels were not clearly visible at final follow-up radiographs causing difficulty in measuring IROM

平移距离、ROM 呈负相关。颈椎椎骨间关节是三关节复合体,椎间盘与关节突关节的运动相耦合;同时,关节突关节间隙与椎间盘间隙处于不同方向,导致颈椎脊柱功能单位(functional spinal unit,FSU)屈伸运动时包含平移与旋转两种椎间运动成分[18]。若椎间旋转运动成分与平移运动成分发生变化,FE-COR-Y 随之改变,旋转增加导致 FE-COR 上移,而平移增加则导致 FE-COR 下移[14,38]。这与本研究结果一致,在平移较少而以旋转为主要椎间运动形式的置换节段,FE-COR 位于椎间盘内,而随着平移距离增加出现 FE-COR 的下移。

平移是上位椎体沿下位椎体上终板表面的滑动,因双凸形椎间盘的支撑,运动轨迹呈弧形[39]。这种弧形滑移会造成相邻椎体成角的变化,故 FSU 的 ROM 被定义为上位椎体相对下位椎体的旋转与平移运动所产生的倾斜角之和[40],随着平移距离的增加会出现 ROM 的增大[14]。本研究发现末次随访时置换节段 ROM 与同节段平移距离呈正相关,印证了该观点。综上,随着平移距离增加会出现 FE-COR 下移及 ROM 增大,因此我们发现置换节段 ROM 越大则 FE-COR 越靠下,二者呈负相关。

屈伸活动时关节突关节的解剖特征可能会影响椎间平移和旋转运动,继而影响 FE-COR 的位置。Penning[39]首先观察到,随着上关节突的高度从 C3 到 C7 逐渐增加,从 C2/3 到 C6/7 的 FE-COR 逐渐上移至椎间盘附近,下颈椎各节段(C2~C7)的 FE-COR 位于同节段关节突关节间隙的中垂线上,且到同节段关节突关节间隙的距离大致相同,由此他提出 FE-COR 位置受同节段 HSAP 与 OZJS 的影响,但没有给出统计学结果进行论证。Milne[12]研究了 67 具人体骨骼标本 C3-T1 椎体的解剖形态,认为关节突关节矢状面朝向(椎间盘-关节突角)会影响平移。椎间盘-关节突角较大(上关节突关节面更趋水平)的节段运动时平移距离更大。Nowitzke 等[11]统计了 40 例正常成人颈椎动力位 X 线片上 C3~C7 椎骨的 HSAP 与 OZJS,发现 HSAP 而非 OZJS 是对应 FSU 的 FE-COR 的重要影响因素,上关节突越高则对应 FE-COR 离该椎体上终板越近。他们认为,FSU 内下位椎体上关节突越高越可能阻挡上位椎体下关节突,减少平移的发生,上关节突的高度决定椎间平移距离。

本研究测量了置换节段的 HSAP、OZJS 与 LSAS,并探索其与同节段 FE-COR、ROM、平移的相关性,发现 FE-COR-Y 与 HSAP 呈正相关,与上述研究的部分结果相似[11,39],而平移、ROM 皆与 HSAP 呈负相关。由此,我们认为平移距离随着 HSAP 的降低而增加,继而出现 FE-COR 的下移与 ROM 的增加。Hybrid 术式中,因 ACDR 并未损伤后方关节突关节,屈伸活动时置换节段在原有关节突关节的引导下可获得术前的平移距离,从而再现术前的 FE-COR 位置与 ROM。这要归功于 Bryan 人工颈椎间盘非限制的封闭髓核结构设计[41]。有研究已证实其可维持置换节段 FE-COR 的位置[42,43]。置换节段屈伸活动时,Bryan 人工椎间盘钛合金上终板在鞘内生理盐水润滑下沿着髓核双凸形表面弧形滑移[44],模拟生理状态下上位椎体相对于下位椎体的平移,而后方的关节突关节通过与 Bryan 人工椎间盘运动的耦合影响屈伸运动时 Bryan 人工椎间盘上终板相对于下终板的滑动距离(即平移距离),最终调整置换节段 FE-COR 与 ROM 至术前状态。

综上,颈椎前路相邻双节段 Hybrid 手术患者中长期随访临床与影像结果满意,置换节段 FE-COR 得到良好的维持,无证据显示融合节段对置换节段运动质量产生明显影响。末次随访时非限制型 Bryan 人工椎间盘与关节突关节运动的耦合使置换节段复制出生理状态下 FE-COR 与平移、HSAP 的关系,这有助于置换节段维持术前 FE-COR,模拟颈椎生理运动模式,理论上可减缓 ASD 的发生。但本研究也存在一定的局限性:(1)因解剖标志不明显导致测量误差大、部分节段 X 线片清晰度欠佳等原因未测量手术相邻节段的 FE-COR,无法直接评估手术相邻节段的运动学质量;(2)未设立接受相邻双节段 ACDF 的对照组,评估 ASD 发生率的高低不够客观;(3)仅观察对比术前与末次随访两个时间点,缺乏对临床疗效与影像结果变化趋势的研究;(4)忽略了两个关节突关节之间解剖参数可能的不同,通过 CT 检查结果测量关节突关节解剖参数有助于提高数据的准确性[12]。(5)融合节段的融合情况理论上可通过改变该节段稳定性而影响相邻置换节段的 FE-COR,但本组病例仅 1 例未骨性融合且相对稳定(ROM<2°),难以分析二者可能存在的关系,未来应扩大样本量进行相关研究。

4 参考文献

1. Hua W, Zhi J, Wang B, et al. Biomechanical evaluation of adjacent segment degeneration after one- or two-level anterior cervical discectomy and fusion versus cervical disc arthroplasty: a finite element analysis [J]. Comput Methods Programs Biomed, 2020, 189: 105352.
2. Findlay C, Ayis S, Demetriades AK. Total disc replacement versus anterior cervical discectomy and fusion: a systematic review with meta-analysis of data from a total of 3160 patients across 14 randomized controlled trials with both short- and medium- to long-term outcomes[J]. Bone Joint J, 2018, 100-B(8): 991-1001.
3. Lavelle WF, Riew KD, Levi AD, et al. Ten-year outcomes of cervical disc replacement with the BRYAN cervical disc: results from a prospective, randomized, controlled clinical trial [J]. Spine(Phila Pa 1976), 2019, 44(9): 601-608.
4. Shin DA, Yi S, Yoon DH, et al. Artificial disc replacement combined with fusion versus two-level fusion in cervical two-level disc disease[J]. Spine(Phila Pa 1976), 2009, 34(11): 1153-1159, 1160-1161.
5. Barbagallo G M, Assietti R, Corbino L, et al. Early results and review of the literature of a novel hybrid surgical technique combining cervical arthrodesis and disc arthroplasty for treating multilevel degenerative disc disease: opposite or complementary techniques[J]. Eur Spine J, 2009, 18(Suppl 1): 29-39.
6. Xiong Y, Xu L, Yu X, et al. Comparison of 6-year follow-up result of hybrid surgery and anterior cervical discectomy and fusion for the treatment of contiguous two-segment cervical degenerative disc diseases[J]. Spine(Phila Pa 1976), 2018, 43(20): 1418-1425.
7. Gandhi AA, Kode S, DeVries NA, et al. Biomechanical analysis of cervical disc replacement and fusion using single level, two level, and hybrid constructs[J]. Spine(Phila Pa 1976), 2015, 40(20): 1578-1585.
8. Martin S, Ghanayem AJ, Tzermiadianos MN, et al. Kinematics of cervical total disc replacement adjacent to a two-level, straight versus lordotic fusion[J]. Spine(Phila Pa 1976), 2011, 36(17): 1359-1366.
9. 周非非, 李舒扬, 赵衍斌, 等. Bryan 颈椎人工间盘置换术术前颈椎退变程度与术后异位骨化相关性的定量分析[J]. 中华医学杂志, 2021, 101(13): 945-949.
10. 孙宇. 加强颈椎人工间盘置换术适应证研究降低异位骨化发生率[J]. 中华医学杂志, 2021, 101(9): 611-614.
11. Nowitzke A, Westaway M, Bogduk N. Cervical zygapophyseal joints: geometrical parameters and relationship to cervical kinematics[J]. Clin Biomech(Bristol, Avon), 1994, 9(6): 342-348.
12. Milne N. The role of zygapophysial joint orientation and uncinate processes in controlling motion in the cervical spine [J]. J Anat, 1991, 178: 189-201.
13. Amevo B, Worth D, Bogduk N. Instantaneous axes of rotation of the typical cervical motion segments: II. optimization of technical errors[J]. Clin Biomech(Bristol, Avon), 1991, 6(1): 38-46.
14. Koller H, Meier O, Zenner J, et al. In vivo analysis of cervical kinematics after implantation of a minimally constrained cervical artificial disc replacement[J]. Eur Spine J, 2013, 22(4): 747-758.
15. Amevo B, Worth D, Bogduk N. Instantaneous axes of rotation of the typical cervical motion segments: a study in normal volunteers[J]. Clin Biomech(Bristol, Avon), 1991, 6(2): 111-117.
16. Amevo B, Macintosh JE, Worth D, et al. Instantaneous axes of rotation of the typical cervical motion segments: I. an empirical study of technical errors[J]. Clin Biomech(Bristol, Avon), 1991, 6(1): 31-37.
17. Liu B, Liu Z, VanHoof T, et al. Kinematic study of the relation between the instantaneous center of rotation and degenerative changes in the cervical intervertebral disc[J]. Eur Spine J, 2014, 23(11): 2307-2313.
18. Reitman CA, Mauro KM, Nguyen L, et al. Intervertebral motion between flexion and extension in asymptomatic individuals[J]. Spine(Phila Pa 1976), 2004, 29(24): 2832-2843.
19. Walraevens J, Liu B, Meersschaert J, et al. Qualitative and quantitative assessment of degeneration of cervical intervertebral discs and facet joints[J]. Eur Spine J, 2009, 18(3): 358-369.
20. Xiong Y, Xu L, Bi LY, et al. Dynamic fusion process in the anterior cervical discectomy and fusion with self-locking stand-alone cages[J]. World Neurosurg, 2019, 125: e678-e687.
21. Amevo B, Aprill C, Bogduk N. Abnormal instantaneous axes of rotation in patients with neck pain [J]. Spine (Phila Pa 1976), 1992, 17(7): 748-756.
22. Faizan A, Goel VK, Biyani A, et al. Adjacent level effects of bi level disc replacement, bi level fusion and disc replacement plus fusion in cervical spine-a finite element based study[J]. Clin Biomech(Bristol, Avon), 2012, 27(3): 226-233.
23. Shin JJ. Comparison of adjacent segment degeneration, cervical alignment, and clinical outcomes after one-and multilevel anterior cervical discectomy and fusion[J]. Neurospine, 2019, 16(3): 589-600.
24. Gao X, Yang Y, Liu H, et al. A comparison of cervical disc arthroplasty and anterior cervical discectomy and fusion in patients with two-level cervical degenerative disc disease: 5-year follow-up results [J]. World Neurosurg, 2019, 122: e1083-e1089.
25. Radcliff K, Coric D, Albert T. Five-year clinical results of cervical total disc replacement compared with anterior discectomy and fusion for treatment of 2-level symptomatic de

generative disc disease: a prospective, randomized, controlled, multicenter investigational device exemption clinical trial[J]. J Neurosurg Spine, 2016, 25(2): 213-224.

26. Davis RJ, Nunley PD, Kim KD, et al. Two-level total disc replacement with Mobi-C cervical artificial disc versus anterior discectomy and fusion: a prospective, randomized, controlled multicenter clinical trial with 4-year follow-up results[J]. J Neurosurg Spine, 2015, 22(1): 15-25.
27. Sang H, Cui W, Sang D, et al. How center of rotation changes and what affects these after cervical arthroplasty: a systematic review and meta-analysis [J]. World Neurosurg, 2020, 135: e702-e709.
28. Bogduk N, Mercer S. Biomechanics of the cervical spine. I: Normal kinematics[J]. Clin Biomech(Bristol, Avon), 2000, 15 (9): 633-648.
29. Anderst W, Baillargeon E, Donaldson W, et al. Motion path of the instant center of rotation in the cervical spine during in vivo dynamic flexion-extension: implications for artificial disc design and evaluation of motion quality after arthrodesis [J]. Spine(Phila Pa 1976), 2013, 38(10): E594-E601.
30. Mo Z, Zhao Y, Du C, et al. Does location of rotation center in artificial disc affect cervical biomechanics[J]. Spine(Phila Pa 1976), 2015, 40(8): E469-E475.
31. Kelly BP, Zufelt NA, Sander E J, et al. The influence of fixed sagittal plane centers of rotation on motion segment mechanics and range of motion in the cervical spine [J]. J Biomech, 2013, 46(7): 1369-1375.
32. Li Y, Zhang Z, Liao Z, et al. Finite element analysis of influence of axial position of center of rotation of a cervical total disc replacement on biomechanical parameters: simulated 2-level replacement based on a validated model[J]. World Neurosurg, 2017, 106: 932-938.
33. Powell JW, Sasso RC, Metcalf NH, et al. Quality of spinal motion with cervical disk arthroplasty: computer-aided radiographic analysis[J]. J Spinal Disord Tech, 2010, 23(2): 89-95.
34. Cunningham BW, Hu N, Zorn CM, et al. Biomechanical comparison of single-and two-level cervical arthroplasty versus arthrodesis: effect on adjacent-level spinal kinematics [J]. Spine J, 2010, 10(4): 341-349.
35. Helgeson MD, Bevevino AJ, Hilibrand AS. Update on the evidence for adjacent segment degeneration and disease [J]. Spine J, 2013, 13(3): 342-351.
36. Hilibrand AS, Robbins M. Adjacent segment degeneration and adjacent segment disease: the consequences of spinal fusion[J]. Spine J, 2004, 4(6 Suppl): 190S-194S.
37. Li XF, Lv ZD, Yin HL, et al. Impact of adjacent pre-existing disc degeneration status on its biomechanics after single-level anterior cervical interbody fusion [J]. Comput Methods Programs Biomed, 2021, 209: 106355.
38. Bogduk N, Amevo B, Pearcy M. A biological basis for instantaneous centres of rotation of the vertebral column [J]. Proc Inst Mech Eng H, 1995, 209(3): 177-183.
39. Penning L. Differences in anatomy, motion, development and aging of the upper and lower cervical disk segments[J]. Clin Biomech(Bristol, Avon), 1988, 3(1): 37-47.
40. White AR, Panjabi MM. The basic kinematics of the human spine: a review of past and current knowledge [J]. Spine (Phila Pa 1976), 1978, 3(1): 12-20.
41. Bryan VJ. Cervical motion segment replacement[J]. Eur Spine J, 2002, 11(Suppl 2): S92-S97.
42. Pickett GE, Rouleau JP, Duggal N. Kinematic analysis of the cervical spine following implantation of an artificial cervical disc[J]. Spine(Phila Pa 1976), 2005, 30(17): 1949-1954.
43. Galbusera F, Fantigrossi A, Raimondi MT, et al. Biomechanics of the C5-C6 spinal unit before and after placement of a disc prosthesis[J]. Biomech Model Mechanobiol, 2006, 5(4): 253-261.
44. Galbusera F, Bellini CM, Raimondi MT, et al. Cervical spine biomechanics following implantation of a disc prosthesis[J]. Med Eng Phys, 2008, 30(9): 1127-1133.

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