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Radiographic and Clinical Outcomes of Transverse Process Hook Placement at the Proximal Thoracic Upper Instrumented Vertebra in Adult Spinal Deformity Surgery

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Objective: Few studies have reported radiographic and clinical outcomes of transverse process hook (TPH) placement at the proximal thoracic upper instrumented vertebra (UIV) in adult spinal deformity (ASD) surgery. This study aims to investigate radiographic and clinical outcomes of TPH placement at the UIV for ASD surgery.
Methods: This is a retrospective cohort of 56 patients with ASD (age, 59 ± 13 years; follow-up, 44 ± 19 months) from Johns Hopkins Hospital, who underwent long posterior spinal fusion to the proximal thoracic spine (T2–5). Visual analogue scale (VAS) for back pain, Oswestry Disability Index (ODI), 36-item Short Form health survey scores, thoracic kyphosis (TK), lumbar lordosis, sacral slope, pelvic tilt, pelvic incidence, proximal junctional kyphosis (PJK) angle, PJK incidence, pattern of PJK, grades of TPH dislodgement, revision surgery, and factors associated with high-grade TPH dislodgement were analyzed.
Results: VAS for back pain and ODI values improved significantly from preoperatively to final follow-up. Mean change in PJK angle was 12° (range, 0.5°–43°). Twenty patients (36%) developed PJK, of whom 13 had compression fractures at 1 vertebra distal to the UIV (UIV–1). Final TPH position was stable in 42 patients (75%). In most patients (86%), TPH dislodgement did not progress after 6-month postoperative follow-up. Three patients (5.3%) underwent revision surgery to extend the fusion because of symptomatic PJK. Unstable TPH position was associated only with revision surgery and TK.
Conclusion: TPH placement at the proximal thoracic UIV for long fusion showed favorable clinical and radiographic outcomes in terms of the incidence of PJK and mean PJK angle at mean 44-month follow-up. TPHs placed in the proximal thoracic UIV were in stable position in 75% of patients. Compression fracture at UIV–1 was the most common pattern of PJK. PJK angle progression was greater in revision cases and in patients with greater preoperative thoracic kyphosis.

Keywords: Adult spinal deformity, Kyphosis, Proximal junctional kyphosis, Proximal thoracic spine, Sagittal imbalance, Scoliosis, Transverse process hook

INTRODUCTION

Proximal junctional kyphosis (PJK) is one of the most common complications after adult spinal deformity (ASD) surgery. The reported incidence ranges from 25% to 66%, varying according to diagnostic criteria, fusion levels, and duration of follow-up, among other factors.[1-6] PJK has adverse effects on clinical outcomes, and revision surgery to extend the fusion is often needed for patients with symptomatic PJK.

Numerous studies have investigated risk factors for PJK.[1-9]

Radiographic risk factors include greater preoperative thoracic kyphosis, excessive correction of sagittal vertical axis (SVA) and lumbar lordosis, greater preoperative pelvic incidence, and inadequate restoration of sagittal balance (e.g., pelvic incidence – lumbar lordosis mismatch). Research suggests that several factors may affect the risk of developing PJK, including UIV fixation method, the number of spinal levels fused, the use of pelvic fixation, patient age, bone mineral density, smoking status, and others.[1-9]

Several studies comparing pedicle screws and transverse process hooks (TPHs) as the UIV fixation method noted a significantly lower incidence of PJK in adult and pediatric spinal deformity patients with TPHs.[3,6,10] Biomechanical cadaver studies have also shown that TPHs reduce stress at the junction between the UIV and proximal segments and allow a more gradual transition of segmental motion compared with pedicle screws in the UIV.[11-13]

Although the use of TPHs at the UIV is becoming more common, little is known about the morphological features, clinical outcomes, and prognostic factors associated with this technique. Therefore, we investigated radiographic and clinical outcomes of patients with ASD after TPH placement at the proximal thoracic UIV for long posterior spinal fusion.

MATERIALS AND METHODS

1. Patient Selection

We retrospectively analyzed data from patients at Johns Hopkins Hospital who underwent long posterior spinal fusion of the proximal thoracic spine that used TPHs at the UIV and pedicle screws distal to the UIV. All surgical procedures were performed by 2 coauthors from 2008 to 2014.

Inclusion criteria were as follows: aged ≥ 20 years at the time of surgery; primary diagnosis of spinal deformity (scoliosis, kyphosis, or kyphoscoliosis) or PJK treated with instrumentation involving a proximal fusion level between T2 and T5; and minimum 2-year clinical and radiographic follow-up. Of 86 patients, we excluded 30 patients for the following reasons: insufficient follow-up (n = 24), Scheuermann kyphosis (n = 3), ankylosing spondylitis (n = 1), traumatic condition (n = 1), and neoplastic condition (n = 1).

This study was approved by the Institutional Review Board (IRB) of Johns Hopkins Hospital (IRB No. 00135145).

2. Surgical Technique

The spine was exposed down to the distal end of the spinous processes, while preserving the interspinous ligaments at the proximal and distal segments, with minimal dissection of the paraspinal muscles. A blunt lamina finder device (DePuy Synthes Spine, Inc., Raynham, MA, USA) was used to prepare the insertion point on the transverse process, ensuring that the TPH blade was immediately lateral to the lateral edge of the pedicle. Care was taken to ensure proper sizing of the TPH so that it could latch to the entire transverse process without weakening or fracturing it.

3. Clinical Outcome Data

We assessed the following clinical outcome measures from patient medical records: visual analogue scale for back pain, Oswestry Disability Index (ODI), and 36-item Short Form health survey (SF-36) physical composite score and mental composite score. We compared changes in scores from the preoperative visit to latest follow-up.

4. Radiographic Analyses

We analyzed 36-inch standing scoliosis radiographs taken at the preoperative visit, 6-week follow-up, and latest follow-up. In addition to PJK angle, sagittal measurements were thoracic kyphosis (T4–12 angle), lumbar lordosis (L1–S1 angle), sacral slope, pelvic tilt, and pelvic incidence. To assess global sagittal spinal alignment, we measured SVA (C7–S1).

We used the following criteria from the study by Glattes et al.[2] to define PJK: (1) presence of a PJK angle (proximal junction sagittal angle of ≥ 10° between the lower endplate of the UIV and the upper endplate of the vertebrae 2 levels proximal to the UIV); and (2) progression of ≥ 10° in the PJK angle from the baseline measurement.

Using lateral radiographs, we assessed the pattern of PJK and the TPH position according to our proposed novel grading system (Fig. 1). Grade 0 indicates no dislodgement or unilateral, incomplete dislodgement of the TPH. Grade 1 indicates bilateral, incomplete dislodgement of the TPH. Grade 2 indicates unilateral or bilateral complete dislodgement of the TPH. Grades 0 and 1 were considered stable positions. We graded TPH position at postoperative follow-up of 6 weeks, 6 months, 12 months, and each subsequent year.

5. Statistical Analyses

We analyzed associations between TPH position and patient demographic characteristics and radiographic and clinical outcomes. We stratified patients by TPH position and compared age, sex, body mass index (BMI) value, preoperative diagnosis,

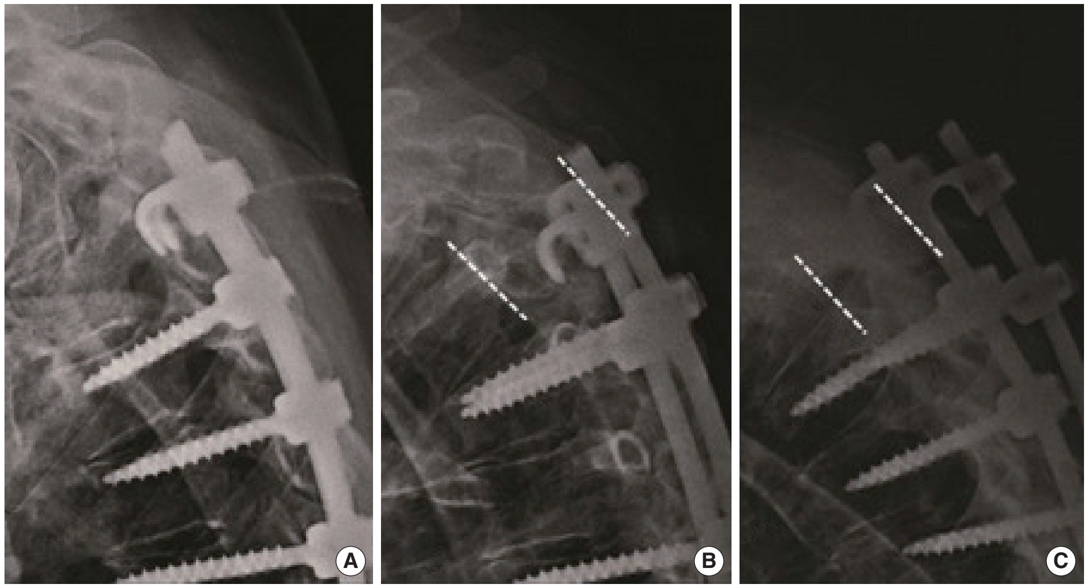

Fig. 1. Lateral radiographs showing the grading system used to assess transverse process hook (TPH) position. The grade of TPH position was based on 2 lines. The anterior dotted line indicates the ventral border of the transverse process, and the posterior dotted line indicates the dorsal border of the rib cage. (A) Grade 0 indicates no dislodgement or unilateral, incomplete dislodgement of the TPH (i.e., the blade of the TPH is between the transverse process and the rib cage). (B) Grade 1 indicates bilateral, incomplete dislodgement of the TPH. (C) Grade 2 indicates unilateral or bilateral complete dislodgement of the TPH (i.e., the blade of the TPH is posterior to the rib cage). Grades 0 and 1 were considered stable positions.

UIV level (T2 or T3 vs. T4 or T5), pelvic incidence, pelvic tilt, lumbar lordosis, thoracic kyphosis, and SVA. We used χ^2 tests to compare categorical variables and analysis of variance to compare continuous variables. Twenty patients were selected randomly for agreement analysis and were reviewed by 2 independent reviewers regarding final position of the TPH. Interrater and intrarater agreement were assessed using the kappa statistic for agreement and the percentage agreement. Statistical analyses were performed using IBM SPSS Statistics ver. 22.0 (IBM Co., Armonk, NY, USA). A p-value < 0.05 was considered statistically significant.

RESULTS

1. Patient Characteristics

Fifty-six patients (43 women) were enrolled. Mean ± standard deviation patient age was 59 ± 13 years, and mean follow-up duration was 44 ± 19 months. The mean preoperative patient BMI value was 29 ± 6.4 kg/m^2. With regards to bone mineral density, the mean lowest preoperative dual-energy X-ray absorptiometry T score was -1.36 ± 1.22. Preoperative diagnoses were primary thoracolumbar kyphoscoliosis in 37 patients and revision for thoracolumbar PJK in 19. The mean number of spinal segments fused was 14 (range, 12–16). The UIV was T2 in 10 patients, T3 in 29 patients, T4 in 15 patients, and T5 in 2 patients (Table 1).

2. Surgical Procedures

Spinal osteotomies were performed in 45 patients (80%), consisting of multilevel posterior column osteotomies (n = 31), pedicle subtraction osteotomies (n = 4), vertebral column resections (n = 3), posterior column osteotomies with pedicle subtraction osteotomies (n = 2 patients), posterior column osteotomies with vertebral column resections (n = 4), and pedicle subtraction osteotomy with vertebral column resection (n = 1). Rod material was titanium in a majority of cases (n = 53), with 3 cases using cobalt chrome rods. Additional surgical procedures during the follow-up period were performed for 9 patients (16%): extension of fusion for new-onset PJK (n = 3) (Table 2), cervical spine surgery (n = 4), and revision surgery for rod fracture (n = 2).

3. Radiographic Outcomes

Thoracic kyphosis and C2–S1 SVA improved significantly from preoperatively to latest follow-up (Table 3). The mean change in PJK angle was 12° (range, 0.5°–43°) at latest follow-up, and radiographic PJK was found in 20 patients (36%). When assessing patterns of PJK, we found that 13 of 20 patients had compression fractures at 1 vertebra distal to the UIV (UIV–1).

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Table 1. Demographic and treatment characteristics of 56 patients who underwent long posterior spinal fusion for adult spinal deformity, 2008–2014

Characteristic	Value
Age (yr)	59 ± 13
Female sex	43 (77)
Body mass index (kg/m²)	29 ± 6.5
Lowest preoperative DEXA T-score	-1.36 ± 1.22
Diagnosis	
Thoracolumbar scoliosis	37 (66)
PJK after thoracolumbar fusion	19 (34)
No. of levels fused	14 ± 1.5
Rod material	
Titanium	53 (95)
Cobalt chrome	3 (5)
Osteotomy type	
Smith-Petersen	31 (55)
Pedicle subtraction	4 (7.1)
Smith-Petersen and pedicle subtraction	2 (3.5)
Vertebral column resection	3 (5.5)
Smith-Petersen and vertebral column resection	4 (7.1)
Pedicle subtraction and vertebral column resection	1 (1.8)
None	11 (20)
Upper instrumented vertebra	
T2	10 (18)
T3	29 (52)
T4	15 (27)
T5	2 (3.6)
Lower instrumented vertebra	
S2 (pelvis)	46 (82)
S1	2 (3.6)
L3	5 (8.9)
L2	1 (1.8)
L1	2 (3.6)
Follow-up duration (mo)	44 ± 19

Values are presented as mean ± standard deviation or number (%).
DEXA, dual-energy X-ray absorptiometry; PJK, Proximal junctional kyphosis.

Other patterns were multiple compression fractures (> 2 vertebrae) (n = 3), screw pullout at UIV–1 (n = 2), compression fracture at the UIV (n = 1), and compression fracture at 2 levels distal to the UIV (UIV–2) (n = 1) (Table 2).

Final TPH position was stable in 42 patients (75%) (grade 0 in 27 patients, grade 1 in 15 patients) and unstable (grade 2) in 14 patients. TPH position did not change after the 6-month postoperative assessment in 48 patients (86%), after the 1-year assessment in 7 patients (12%), and after the 2-year assessment in 1 patient.

Table 2. Complications in patients with adult spinal deformity after long posterior spinal fusion with transverse process hooks at the proximal thoracic UIV

Complication	No. of patients (%)
Revision surgery causes	9 (16)
Surgery for additional PJK	3 (33)
Surgery for cervical spine problem	4 (44)
Revision for rod fracture	2 (22)
Patterns of PJK	20 (36)
Compression fracture at UIV	1 (5)
Compression fracture at UIV–1	13 (65)
Compression fracture at UIV–2	1 (5)
Multiple compression fractures	3 (15)
Screw pullout at UIV–1	2 (10)

UIV, upper instrumented vertebra; PJK, proximal junctional kyphosis; UIV–1, 1 vertebra distal to the UIV; UIV–2, 2 vertebra distal to the UIV.

4. Clinical Outcomes

VAS for back pain and ODI values improved significantly from preoperatively to final follow-up (Table 3). However, SF-36 scores did not change significantly between preoperatively and final follow-up. Nine patients required revision surgery following TPH fixation. Indications for revision included surgery for additional PJK (n = 3), surgery for additional cervical spine problems (n = 4), and revision for rod fracture (n = 2).

5. Associations Between TPH Position and Other Parameters

Only 2 parameters—revision surgery and greater preoperative thoracic kyphosis—were associated with unstable final TPH position (both, $p < 0.001$) (Table 4). We found no significant associations between final TPH position and patient sex, age, or BMI; level of the UIV; pelvic incidence; preoperative pelvic tilt, lumbar lordosis, or SVA; or correction of pelvic tilt, lumbar lordosis, thoracic kyphosis, or SVA.

6. Intrarater and Interrater Agreement

Based on data from 20 randomly selected patients, interrater agreement was 80% (kappa = 0.70) and intrarater agreement was 90% (kappa = 0.85) regarding final position of TPH.

Table 3. Radiographic and clinical parameters for 56 patients who underwent long posterior spinal fusion for adult spinal deformity, 2008–2014

Variable	Preoperative	Immediate postoperative	Follow-up*	p-value
Radiographic parameters				
C7–S1 SVA (mm)	40 ± 69	15 ± 31	19 ± 43	0.038
Lumbar lordosis (°)	41 ± 24	48 ± 11	45 ± 14	0.271
Pelvic incidence (°)	57 ± 15			
Pelvic tilt (°)	28 ± 14	26 ± 12	26 ± 14	0.512
Sacral slope (°)	30 ± 16	32 ± 11	31 ± 11	0.644
Thoracic kyphosis (°)	52 ± 19	46 ± 16	47 ± 16	0.040
Clinical parameters				
ODI	52 ± 23	-	27 ± 21	< 0.001
SF-36-MCS	41 ± 14	-	44 ± 15	0.550
SF-36-PCS	36 ± 7.7	-	41 ± 15	0.140
VAS for back pain	5.5 ± 2.5	-	3.7 ± 2.2	0.017

Values are presented as mean ± standard deviation.
SVA, sagittal vertical axis; ODI, Oswestry Disability Index; SF-36, 36-item Short Form health survey; MCS, mental composite score; PCS, physical composite score; VAS, visual analogue scale.
*Mean ± standard deviation follow-up was 44 ± 19 months.

DISCUSSION

In addition to the incidence of PJK, we investigated radiographic features, clinical outcomes, and factors related to TPH placement at the proximal thoracic UIV for long posterior spinal fusion. TPHs placed at the UIV were in stable position (grade 0 or 1) in 75% of patients, and TPH position did not change after 6 months postoperatively in most patients. Unstable TPH position was more common in patients who underwent surgery for PJK after previous thoracolumbar fusion than among patients who underwent primary deformity surgery, as well as in patients who had greater preoperative thoracic kyphosis. The incidence of PJK was 36%, and most cases of PJK consisted of compression fracture at UIV–1. Revision surgery for new-onset PJK was performed in 3 patients (5.3%) during a mean follow-up period of 44 months. Interrater and intrarater agreement when determining the final position of the TPH were 80% and 90%, respectively.

The effect of the load distribution for UIV fixation on the risk of PJK has been investigated in clinical and biomechanical studies.[8-13] Kim et al.[6] reported a lower incidence of PJK when using TPHs versus pedicle screws in pediatric patients with scoliosis. Those results were similar to findings of a subsequent study by Helgeson et al.,[3] demonstrating a 5.6° change in the screw group compared with a 1.4° change in the TPH group. In 2013, Hassanzadeh et al.[10] compared the use of TPHs versus pedicle screws for UIV fixation in 47 patients with ASD. The authors reported a significantly lower incidence of PJK in the TPH group (0 of 20) compared with the screw group (8 of 27) ($p = 0.01$) at a mean follow-up of 2.8 years.

Biomechanical research supports clinical findings of the superiority of TPH to pedicle screws.[11-13] The stiffness of constructs using TPHs was significantly lower than that of constructs using pedicle screws in porcine and cadaveric spines.[11-13] Moreover, TPH constructs maintained a pattern of monotonic increase in mean range of motion from distal to proximal and showed lower supra-adjacent hypermobility compared with UIV pedicle screw constructs, which had the greatest mean range of motion at the first uninstrumented segment.[11-13]

We are aware of no previous studies that have assessed TPH position and its change over time. Although nearly 50% of our cohort had stable, grade 1 TPH position, the remaining patients had a variable degree of dislodgement. This dislodgement may be similar to the loosening of pedicle screws at the UIV, which is typically associated with pseudarthrosis at the affected level. However, unlike pedicle screw loosening, TPH dislodgement may represent natural repositioning during follow-up and may provide the construct with a transitional level of motion from the proximal unfused segment to the distal fused segments. In most patients, TPH position did not change after 6-month follow-up, which may suggest that the adaptation period of TPHs is approximately 6 months. The low incidence of revision sur-

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Table 4. Characteristics of 56 patients with adult spinal deformity by final* proximal transverse hook position

Characteristic	Position of proximal transverse hook						p-value
	Grade 0 (n = 26)		Grade 1 (n = 16)		Grade 2 (n = 14)		
	No.	Mean ± SD	No.	Mean ± SD	No.	Mean ± SD	
Age (yr)		57 ± 15		60 ± 13		61 ± 12	0.561
Sex							0.817
Female	20		13		10		
Male	6		3		4		
BMI (kg/m^2)		26 ± 4.8		29 ± 8.6		30 ± 6.2	0.268
Diagnosis							0.004
Primary deformity	23		8		6		
Revision for PJK	3		8		8		
UIV level							0.156
T2 or T3	19		13		7		
T4 or T5	7		3		7		
Follow-up duration (mo)		44 ± 16		48 ± 24		39 ± 18	0.486
Radiographic parameters (°)							
Lumbar lordosis							
Preoperative		38 ± 28		46 ± 19		41 ± 22	0.600
Change		11 ± 26		1.9 ± 17		0.7 ± 19	0.150
Pelvic incidence		61 ± 12		54 ± 19		55 ± 12	0.267
Pelvic tilt							
Preoperative		31 ± 12		25 ± 20		27 ± 8.5	0.453
Change		4.1 ± 13		0.4 ± 15		2.3 ± 10	0.656
Sagittal vertical axis							
Preoperative		35 ± 62		41 ± 59		42 ± 92	0.953
Change		24 ± 48		25 ± 57		20 ± 77	0.973
Thoracic kyphosis							
Preoperative		46 ± 20		56 ± 16		60 ± 15	0.040
Change		3.1 ± 17		8.7 ± 14		5.4 ± 18	0.569

Grade 0, no dislodgement or unilateral, incomplete dislodgement of the transverse process hook (TPH); grade 1, bilateral, incomplete dislodgement of the TPH; grade 2, unilateral or bilateral complete dislodgement of the TPH. Grades 0 and 1 were considered stable position.
SD, standard deviation; BMI, body mass index; PJK, proximal junctional kyphosis; UIV, upper instrumented vertebra.
*Mean ± standard deviation follow-up was 44 ± 19 months.

gery for new-onset PJK (5.3%) and a mean change in PJK angle of 12° may further support this theory.

The 36% incidence of PJK in our cohort is similar to that reported in previous case series. However, if we were to use a different definition of PJK, based on a threshold of 20°[1] rather than 10º, the incidence in our cohort would be 18% (10 of 56 patients), which is comparable to the findings of previous studies using that criterion.

The indication for surgery may be associated with the progression of PJK angle and final TPH position. Patients who underwent surgery for PJK after a previous fusion had a higher incidence of unstable TPH position and PJK angle progression than patients who underwent primary thoracolumbar fusion. Various factors, including bone and soft tissue conditions and tendencies of some patients to develop a stooping posture, may contribute to this finding.

When analyzing the patterns of PJK after TPH UIV fixation, we found that 65% of patients had a compression fracture at UIV–1. This finding could be explained by the fact that TPHs do not stabilize the anterior spinal column. If further mechanical augmentation, such as preventive vertebroplasty, were to be provided at UIV−1, a substantial proportion of cases of PJK after this procedure may be potentially prevented.

This study has several limitations. First, we lacked information regarding fusion status from flexion-extension radiographs or computed tomography. Second, 24 of 80 otherwise eligible patients had less than 2-year follow-up and were excluded from analysis. Third, this is a retrospective case series that is subject to all limitations inherent in such a design, as well as selection bias. Lastly, this study was performed at a tertiary care academic center with a unique patient population. Such findings should be interpreted with caution when extrapolating to different clinical setting. However, we believe this is the first study to describe the detailed morphological features of TPH placement for UIV fixation at the proximal thoracic spine in patients with ASD. Our study underscores the need for future comparative studies to examine differences in clinical outcomes by TPH position.

CONCLUSION

TPH placement at the proximal thoracic UIV for long fusion showed favorable clinical and radiographic outcomes in terms of the incidence of PJK and mean PJK angle. In 75% of patients treated with long posterior spinal fusion for ASD, TPHs placed in the proximal thoracic spine at the UIV were in a stable position at minimum 2-year follow-up. In most patients, TPH position did not change after the first 6 months postoperatively. Compression fracture at UIV−1 was the most common pattern of PJK. PJK angle progressed significantly more in patients with greater preoperative thoracic kyphosis and in those with PJK after previous thoracolumbar fusion.

NOTES

Conflict of Interest: The authors have nothing to disclose.

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Author Contribution: Conceptualization: SHL, MR; Data curation: SHL; Formal analysis: SHL, MR, AHK; Methodology: SHL, MR; Project administration: MR; Visualization: MR; Writing – original draft: SHL, MR; Writing – review & editing: SHL, MR, AHK, DBC, KMK.

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