

RESEARCH ARTICLE

The Relationship between T1 Sagittal Angle and Sagittal Balance: A Retrospective Study of 119 Healthy Volunteers

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Abbreviations: maxTK, Maximum thoracic kyphosis; maxLL, Maximum lumbar lordosis; LL, Lumbar lordosis; TK, Thoracic kyphosis; SS, Sacrum slope; PT, Pelvic tilt; PI, Pelvic incidence; SVA, Sagittal vertical axis; TPA, T1 pelvic angle; T1SPI, T1 spinopelvic inclination; HRQOL, Health-related quality

Abstract

T1 sagittal angle has been reported to be used as a parameter for assessing sagittal balance and cervical lordosis. However, no study has been performed to explore the relationship between T1 sagittal angle and sagittal balance, and whether T1 sagittal angle could be used for osteotomy guidelines remains unknown. The aim of our study is to explore the relationship between T1 sagittal angle and sagittal balance, determine the predictors for T1 sagittal angle, and determine whether T1 sagittal angle could be used for osteotomy guidelines to restore sagittal balance. Medical records of healthy volunteers in our outpatient clinic from January 2014 to August 2015 were reviewed, and their standing full-spine lateral radiographs were evaluated. Demographic and radiological parameters were collected and analyzed, including age, gender, T1 sagittal angle, maxTK, maxLL, SS, PT, and PI. Correlation coefficients between T1 sagittal angle and other spinopelvic parameters were determined. In addition, multiple regression analysis was performed to establish predictive radiographic parameters for T1 sagittal angle as the primary contributors. A total of 119 healthy volunteers were recruited in our study with a mean age of 34.7 years. It was found that T1 sagittal angle was correlated with maxTK with very good significance ($r = 0.697, P < 0.001$), maxLL with weak significance ($r = 0.206, P = 0.024$), SS with weak significance ($r = 0.237, P = 0.009$), PI with very weak significance ($r = 0.189, P = 0.039$), SVA with moderate significance ($r = 0.445, P < 0.001$), TPA with weak significance ($r = 0.207, P = 0.023$), and T1SPI with weak significance ($r = 0.309, P = 0.001$). The result of multiple regression analysis showed that T1 sagittal angle could be predicted by using the following regression equation: $T1\ sagittal\ angle = 0.6 * maxTK - 0.2 * maxLL + 8$. In the healthy population, T1 sagittal angle could be considered as a useful parameter for sagittal balance; however, it could not be thoroughly replaced for SVA. maxTK was the primary contributor to T1 sagittal angle. According to this equation, we could restore sagittal balance by surgically changing thoracic kyphosis and lumbar lordosis, which could serve as a guideline for osteotomy.

of life; SPO, Smith-Petersen osteotomy; PSO, Pedicle subtraction osteotomy; VCR, Vertebral column resection.

Introduction

Many studies [1–4] have demonstrated that sagittal balance rather than coronal balance is significantly correlated with health-related quality of life (HRQOL), especially in patients who received surgical treatment because sagittal imbalance after spinal surgery may be a primary contributor to pain and disability. Therefore, more attention is often paid to sagittal balance than to coronal balance during the pre- and post-operative deformity assessment, surgical plan-making and surgical procedure [5,6].

Sagittal vertical axis (SVA) refers to the distance between the center of the body of C7 and the posterior-superior edge of S1, and is commonly used as gold standard to evaluate sagittal balance during assessment of spinal sagittal plane deformities [7–10]. Although SVA is regarded as the gold standard of evaluating sagittal balance, it is likely to produce measurement errors because it neglects the position of the head and cervical spine [9,10] and fails to take into account the pelvic compensation [11]. In addition, it is greatly affected by the patient's posture. All these demerits have urged spinal surgeons to search for better parameters to assess sagittal balance.

T1 sagittal angle, the angle between a horizontal line and the cranial end plate of T1, is a novel parameter for evaluating the whole sagittal balance with fewer measurement errors because it takes into account the head position. Therefore, it is better correlated with SVA and could be utilized where long films cannot be obtained [9]. But whether T1 sagittal angle could represent sagittal balance more accurately than other sagittal parameters including SVA, TPA (T1 pelvic angle) and T1SPI (T1 spinopelvic inclination) remains unclear. In addition, our team has found great impacts of lumbar lordosis (LL) and thoracic kyphosis (TK) on maintenance and prediction of sagittal balance, which are considered novel regional predictors for sagittal balance [12,13]. Therefore, we speculated that LL and TK may be important contributors to T1 sagittal angle and sagittal balance, and we could restore sagittal balance through T1 sagittal angle by changing TK and LL in the surgical procedure. The aim of the present study was to explore the relationship between T1 sagittal angle and sagittal balance, compare T1 sagittal angle with other sagittal parameters, and determine the predictors for T1 sagittal angle in normal populations, hoping that the results of the study could provide guidance for osteotomy by changing these primary contributors in correction surgery.

Materials and Methods

Patient population

A total of 119 healthy volunteers in our outpatient clinic from January 2014 to August 2015 who met the inclusion and exclusion criteria were retrospectively reviewed. The inclusion criteria were as follows: 1) younger than 60 years; 2) no history of spinal disorders and spine surgery; and 3) no history of lower back pain (at least 6 months before participation in this study) and radiological abnormalities. The exclusion criteria were as follows: 1) a definite diagnosis of lumbar spinal pathology and spinal deformities, including tumors or infections; and 2) hip, knee and ankle abnormalities. Subjects without sufficient radiographic parameters were also excluded from our study. This study was approved by the Institutional Review Board of Changhai Hospital, and all patients in our study provided written informed consent for the study.

Data collection

Demographic data including gender and age were collected. Radiographic parameters of the whole spine were measured in a lateral position by two surgeons independently, including T1 sagittal angle (the angle between a horizontal line and the superior end plate of T1), maxTK

(thoracic kyphosis calculated by the Cobb method), maxLL (lumbar lordosis calculated by the Cobb method), SS (the angle between the horizontal and the sacral plate), PT (the angle between the vertical and the line through the midpoint of the sacral plate to femoral heads axis), PI (angle subtended by a perpendicular from the upper endplate of S1 and a line connecting the center of the femoral head to the center of the upper endplate of S1), SVA (the horizontal offset from the posterosuperior corner of S1 to the vertebral body of C7), T1 pelvic angle (TPA, the angle between the line from the femoral head axis to the centroid of T1 and the line from the femoral head axis to the middle of the S1 endplate), and T1SPI (T1 spinopelvic inclination, the angle between the line from the femoral head axis to the centroid of T1 and the plummet line). Correlation coefficients between T1 sagittal angle and other sagittal parameters were determined, multiple regression analysis was conducted to find out the primary contributors to T1 sagittal angle, and further, adjusted multiple regression analysis was conducted using morphologic parameters (maxTK and maxLL) to establish predictive radiographic parameters and formula for T1 sagittal angle.

Statistical analysis

Statistical analyses were performed using SPSS 17.0 statistics software (SPSS Inc., Chicago, IL). Descriptive statistics were listed in the form of mean and standard deviation. T1 sagittal angle and its correlation with radiographic parameters were analyzed by correlation coefficient test. Unadjusted multiple regression analysis was performed to detect primary contributors to T1 sagittal angle using parameters that were significantly correlated with T1 sagittal angle in the correlation coefficients analysis, and adjusted multiple regression analysis was conducted to find out the regression equation using morphologic parameters (maxTK and maxLL) to predict T1 sagittal angle. $P < 0.05$ was selected as significant level.

Results

A total of 119 healthy volunteers (M: 61; F: 58) were recruited in our study with the mean age of 34.7 years. The mean T1 sagittal angle, maxTK, maxLL, SS, PT, PI, SVA, TPA and T1SPI were 19.76°, 35.80°, 50.18°, 34.34°, 12.95°, 47.29°, 2.76mm, 8.28° and -4.67° (Table 1). In addition, no significant difference in demographic and radiological parameters was observed between males and females (all $P > 0.05$) (Table 2).

T1 sagittal angle was correlated with maxTK with very good significance ($r = 0.697$, $P < 0.001$), maxLL with weak significance ($r = 0.206$, $P = 0.024$), SS with weak significance ($r = 0.237$, $P = 0.009$), PI with very weak significance ($r = 0.189$, $P = 0.039$), SVA with moderate

Table 1. General characteristics and radiographic parameters of the healthy population included in this study.

Variable	Mean	Standard deviation	Minimum	Maximum
Age (years)	34.71	13.81	11	58
T1 sagittal angle (°)	19.76	5.79	5	33
maxTK (°)	35.80	8.54	20	71
maxLL (°)	50.18	9.71	24	88
SS (°)	34.34	6.96	17	57
PT (°)	12.95	6.42	-2	27
PI (°)	47.29	9.58	28	78
SVA (mm)	2.76	21.59	-58	49
TPA (°)	8.28	5.82	-6	25
T1SPI (°)	-4.67	3.45	-13	5

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Table 2. General characteristics in different genders.

Variable	Male (Mean±Standard deviation)	Female (Mean±Standard deviation)	P value
Age (years)	33.77±12.88	35.71±14.77	0.447
T1 sagittal angle (°)	19.70±5.82	19.81±5.81	0.921
maxTK (°)	35.56±9.18	36.05±7.88	0.754
maxLL (°)	50.36±10.75	50.00±8.57	0.840
SS (°)	34.89±7.28	33.78±6.62	0.387
PT (°)	13.44±5.18	12.43±7.51	0.397
PI (°)	48.33±9.41	46.21±9.71	0.229
SVA (mm)	4.80±21.50	0.60±21.67	0.291
TPA (°)	8.98±4.90	7.53±6.61	0.179
T1SPI (°)	-4.46±3.11	-4.90±3.79	0.494

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significance ($r = 0.445$, $P < 0.001$), TPA with weak significance ($r = 0.207$, $P = 0.023$), and T1SPI with weak significance ($r = 0.309$, $P = 0.001$), while no significant correlation was observed between T1 sagittal angle and the other radiological parameters (Table 3). In addition, a strong correlation was observed between T1 sagittal angle and maxTK (Fig 1).

Unadjusted multiple linear regression analysis was conducted by using variables that were found to be significantly correlated with T1 sagittal angle in the correlation coefficients analysis, and the results suggested that maxTK, maxLL and SS were the primary contributors to T1 sagittal angle (all $P < 0.001$), while there was no significant correlation between T1 sagittal angle and PI ($P = 0.589$) (Table 4). Since it was difficult to predict the postoperative values of compensatory parameters such as SS accurately before correction surgery; therefore, we removed SS from the multiple regression equation. Adjusted regression analysis showed that maxTK and maxLL were significantly associated with T1 sagittal angle, which could be predicted by using the following regression equation: T1 sagittal angle = $0.6 * \text{maxTK} - 0.2 * \text{maxLL} + 8$, as shown in Table 4.

Discussion

Rebalancing sagittal balance is considered to be more important than correcting the coronal spinal deformity in the spinal surgery because sagittal balance has been demonstrated to be significantly correlated with HRQOL [14–17]. The whole sagittal balance can be evaluated by SVA, TPA, T1 sagittal angle and T9 sagittal offset [9,18,19]. However, each parameter has its own merits and demerits [9,11,18]. Among these parameters that reflect the whole sagittal balance, T1 sagittal angle might be an ideal measure compared with the others, and therefore

Table 3. Correlation between T1 sagittal angle and other variables.

Variables	Pearson correlation coefficient (r)	P value
Age (years)	0.111	0.229
maxTK (°)	0.699	$P < 0.001$
maxLL (°)	0.209	0.023
SS (°)	0.239	0.009
PT (°)	0.023	0.806
PI (°)	0.189	0.039
SVA (mm)	0.452	$P < 0.001$
TPA (°)	0.208	0.023
T1SPI (°)	0.309	0.001

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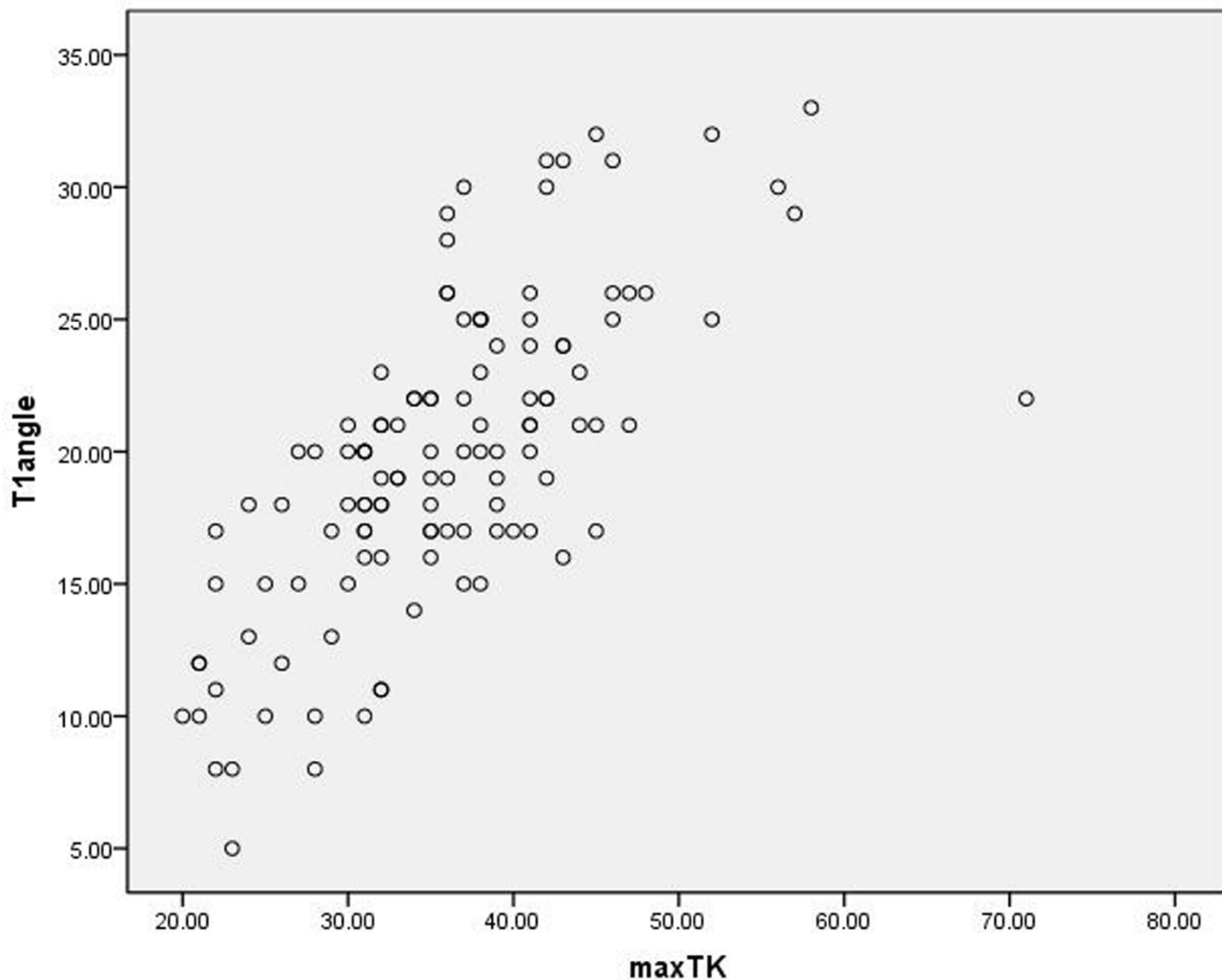


Fig 1. Correlation between T1 sagittal angle and maxTK for the healthy volunteers.

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Table 4. Multiple regression analysis on T1 sagittal angle and maxTK, maxLL, SS and PI.

	B	Standard error	t	P value
Unadjusted				
Constant	-0.067	0.764	-0.087	0.930
maxTK	0.982	0.021	45.730	P<0.001
maxLL	-0.966	0.030	-32.163	P<0.001
SS	0.951	0.041	22.997	P<0.001
PI	0.010	0.019	0.542	0.589
Adjusted				
Constant	8.537	1.873	4.558	P<0.001
maxTK	0.646	0.053	12.248	P<0.001
maxLL	-0.237	0.046	-5.111	P<0.001

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could be used easily when long-standing radiographs are not available. In addition, T1 sagittal angle is associated with lesser measurement errors as compared with distance measurement such as SVA, although it also needs to be perfected.

Several methods and techniques have been used to restore sagittal balance during surgery in clinical practices [20–22]. Spine osteotomies, including Smith–Petersen osteotomy (SPO), pedicle subtraction osteotomy (PSO) and vertebral column resection (VCR) and etc. are the commonly used methods to restore alignment of the spine [23,24], although several disadvantages have been recognized, such as longer operation time, larger blood loss, and higher revision rates. Therefore, it is urgent to detect primary factors and predictors for sagittal balance so that we could restore sagittal alignment through changing these factors in the surgical process, which could provide guidance for osteotomy selection.

In our previous study, T1 sagittal angle, together with age and PT, was found to be one of the three primary contributors to maintaining sagittal balance. As pelvic parameters play a role in compensatory mechanisms [25], finding out the possible factors for T1 sagittal angle might be as equally important as finding out the predictors for the whole sagittal balance. In addition, our previous study [12,13] also found that LL and TK were important contributors to sagittal balance. Therefore, we speculated that LL and TK might play a role in maintaining T1 sagittal angle and could be changed in the surgical procedure through osteotomy to restore the whole sagittal balance. However, few studies have been performed to explore the relationship between T1 sagittal angle and spine sagittal parameters, such as LL and TK [9,10,26]. Therefore, we conducted this retrospective study to determine the relationship between T1 sagittal angle and sagittal balance, predictors for T1 sagittal angle, and whether T1 sagittal angle could be used for osteotomy guidelines to restore sagittal balance.

It was found in our study that T1 sagittal angle was statistically correlated to SVA with moderate significance ($r = 0.445$, $P < 0.001$), which is consistent with the finding of Knott et al [9], who reported that the value of correlation between T1 sagittal angle and SVA was 0.65 ($P < 0.001$), which is larger than that reported in our study. This difference may be explained by the significant difference in sample size (119 vs. 52) and measurement errors between the two studies. Furthermore, we also explored the correlation between T1 tilt angle and other whole sagittal parameters (TPA and T1SPI) that were not studied in previous studies. We found that T1 sagittal angle was also correlated with TPA and T1SPI, with weak significance of 0.207 ($P = 0.023$) and 0.309 ($P = 0.001$), respectively. As T1 sagittal angle was correlated with three parameters that reflected the whole sagittal balance, we could consider T1 sagittal angle as a good predictor of overall sagittal balance, which was also reported in the study of Knott et al [9], although it has its own limits, such as not very strong significance between T1 sagittal angle and whole sagittal balance. Our correlation analysis also showed correlations between T1 sagittal angle and maxTK, maxLL, SS and PI. The significant correlation between T1 sagittal angle and maxTK and maxLL verifies our previous finding that regional spinal parameters (TK and LL) play a key role in maintaining sagittal balance, which also reflects a chain of correlation between regional sagittal parameters [10]. SS was also found to be significantly correlated with T1 sagittal angle, which can be easily understood because the geometric relationship has been verified: $T1 \text{ sagittal angle} = SS - (\max LL - \max TK)$ (maxTK was usually measured from T1 to T12, and maxLL was measured from L1 to S1). Besides, T1 sagittal angle was also found to be correlated with PI, a morphologic parameter used to define lumbar alignment [27]. Because it is generally accepted that increased PI is due to alteration of the overall anthropometric morphology and twisting mobilization of the sacro-iliac joints induced by the biomechanical conditions of sagittal disturbance [28,29]. Sagittal balance can be maintained through three main compensatory mechanisms that could occur in the spine, pelvis and/or lower limb areas, including reduction of TK/hyperextension of adjacent segments, pelvis retroversion (increase

of PT and rotation of the pelvis), knee flexion and ankle extension [30,31]. Hyperextension of the adjacent segments is a common compensatory mechanism in keeping sagittal balance, for pelvis retroversion, knee flexion and ankle extension may occur secondary to hyperextension of the adjacent segments if these segments are too rigid to extend or reach their limits [30,32]. Our unadjusted and adjusted multiple regression analyses showed that TK and LL were two important predictors for T1 sagittal angle, and our unadjusted analysis showed that maxTK, maxLL and SS were primary contributors to T1 sagittal angle. However, PI was not included in the final regression equation in our study. It is widely believed that PI is described and considered unchanged in adulthood as long as the sacroiliac joints remain stable. Therefore, it might not be important contributor to the whole sagittal balance [29,33]. In the adjusted analysis, we removed SS from the equation as all the people recruited in our study were healthy volunteers without any spinal diseases and their sagittal alignment was balanced without any secondary compensatory mechanisms, such as pelvic retroversion, knee flexion and ankle extension. In addition, since pelvic parameters play a role in compensatory mechanisms [25], SS might not be a primary contributor to T1 sagittal angle and sagittal balance in healthy populations. Therefore, our final results showed that T1 sagittal angle could be predicted by using the following regression equation: $T1 \text{ sagittal angle} = 0.6 * \text{maxTK} - 0.2 * \text{maxLL} + 8$, which further verifies the previous opinion that reduction of TK/hyperextension of the adjacent segments was an important compensatory mechanism and our previous finding that regional spinal parameters (TK and LL) played a key role in maintaining sagittal balance. Furthermore, we should also notice that maxTK plays a more important role in sagittal balance than maxLL as the coefficients of maxTK and maxLL were 0.6 and 0.2, respectively.

In the healthy population, sagittal alignment maintains balance through changing TK and LL as shown in regression equation ($T1 \text{ sagittal angle} = 0.6 * \text{maxTK} - 0.2 * \text{maxLL} + 8$), which could also provide guidelines for surgery. With increased awareness of the importance of sagittal balance in HRQOL, many surgeons pay more attention to the restoration of sagittal alignment than coronal imbalance. Therefore, our findings could provide guidelines for osteotomy because spinal surgeons could restore sagittal balance easily by changing TK and LL more easily than SS, and restore the normal relationship between TK and LL during surgery.

Although we found that TK and LL were two primary contributors to sagittal balance in healthy populations, there are some limitations in this study. First, all the subjects recruited in this study came from the outpatient clinic of our hospital, which might result in selection bias. Second, our study was a single-center study and the sample size was relatively small. Third, normative values and reliability studies for T1 sagittal balance were also neglected. Therefore, larger-scale and multicenter studies are required to gain more comprehensive insights into predictors for T1 sagittal angle in normal populations.

Conclusion

T1 sagittal angle could be considered a useful parameter for sagittal balance in healthy populations, though it could not fully replace SVA. maxTK is the primary contributor to T1 sagittal angle, and could be predicted by using the following equation: $T1 \text{ sagittal angle} = 0.6 * \text{maxTK} - 0.2 * \text{maxLL} + 8$, whereby we could restore sagittal balance by surgically changing TK and LL. These findings may provide useful information for osteotomy.

Supporting Information

S1 File. The raw data of our article.
(XLSX)

Author Contributions

Conceptualization: MY.

Data curation: MY.

Formal analysis: CY.

Investigation: CY.

Methodology: CY.

Project administration: ML.

Resources: YZ.

Software: HN MY.

Supervision: ML.

Validation: YZ MY.

Visualization: ML.

Writing - original draft: YZ.

Writing - review & editing: MY.

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