CLINICAL ARTICLE

The Difference of Sagittal Correction of Adult Subaxial Cervical Spine Surgery According to Age: A Retrospective Study

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Objective: At present, the true sagittal alignment of the cervical spine is uncertain, resulting in no standard reference for subaxial cervical surgery. So, we aimed to explore the age difference of normal cervical sagittal alignment and to further investigate the mid-and long-term changes of sagittal alignment after subaxial cervical spine surgery.

Materials and Methods: This was a retrospective study and 1223 asymptomatic volunteers and 79 patients undergoing subaxial cervical spine surgery were retrospectively reviewed in total. Asymptomatic volunteers and patients were divided into six subgroups: 20–29, 30–39, 40–49, 50–59, 60–69 and ≥70 groups. The age difference and trend with age of cervical sagittal parameters of asymptomatic volunteers were assessed by cervical lateral radiography and analyzed by ANOVA test, and the regression equation of C2-7 Cobb was established via multiple linear regression. Based on the C2-7 Cobb regression equations of different ages, the theoretical value, deviation value, loss value of the C2-7 Cobb, and JOA recovery rate of patients were calculated, and the correlation among the loss value, deviation value of the C2-7 Cobb, and JOA recovery rate of the 79 patients was evaluated by Pearson correlation analysis.

Results: For the asymptomatic volunteers, the C0-2 Cobb decreased gradually with increasing age. The C2-7 Cobb, C2-7 SVA, T1S, NT, and TIA increased gradually with increasing age. The CBVA fluctuated with increasing age. T1S demonstrated a moderate correlation with C2-7 Cobb ($r = 0.60$, $p < 0.01$); C0-2 Cobb, C2-7 SVA, CBVA, and TIA demonstrated a fair correlation with C2-7 Cobb ($r = -0.30$, -0.33, 0.41, 0.40, $p < 0.01$); age demonstrated a poor correlation with C2-7 Cobb ($r = 0.19$, $p < 0.01$). The regression equations of C2-7 Cobb were established using C0-2 Cobb, C2-7 SVA, CBVA, and T1S. For the patients with subaxial cervical spine surgery, the loss of C2-7 Cobb was moderately correlated with the deviation of C2-7 Cobb ($r = 0.33$, $p < 0.01$).

Conclusion: The age difference of cervical sagittal alignment was obvious, and the C2-7 Cobb increased with age especially. The closer the postoperative C2-7 Cobb was to the theoretical value of corresponding age, the smaller the

loss of correction angle was, and the better the mid- and long-term outcomes. The personalized sagittal reconstruction should be performed according to age difference for subaxial cervical spine surgery.

Key words: age difference; cervical spine; individualized; sagittal correction

Introduction

The common diseases of subaxial cervical spine mainly include various types of degenerative cervical spondylosis, cervical tumor, cervical trauma, cervical developmental deformity, and cervical infectious diseases. Subaxial cervical spine surgery is the most effective treatment method in the late stage of subaxial cervical spine disease.

The aims of surgical treatment are to completely alleviate the compression of dural sac, reconstruct the stability of the cervical spine, and restore the curvature of the cervical spine in accordance with the biomechanical characteristics.[2–4] Decompression and stabilization have been recognized surgical goals, and the techniques are generally well-established. With the research progresses of sagittal balance, it is taken more and more seriously for cervical sagittal alignment. Cervical sagittal balance was closely related to clinical prognosis.[4–10] Therefore, the restoration of cervical spine alignment is a hot topic in recent years.

At present, the standard of sagittal correction for subaxial cervical spine surgery has not been uniform.[11] There are mainly five different viewpoints as follows. Kota et al. proposed that it should be corrected when the local kyphosis angle >13°.[12] Michael et al. presented that the cervical spine alignment should be restored to a straight curvature (i.e. without kyphosis or lordosis).[13] Ames et al. proposed that we should keep the T1S-Cl < 15°, C2-7 SVA < 40 mm[1]. Tundo et al. suggested that cervical lordosis or neutral alignment should be restored.[3] Dennis et al. believed that it should not be forced to correct cervical lordosis, and the goal of sagittal correction should be personalized.[14] However, the above guidelines were not easy to grasp in practice and did not take the age difference of cervical alignment into consideration. We make it mainly based on the experience of the surgeon and the existing references from literature, and great differences exist in clinical practice.[1,3,12–14] Moreover, distinct age differences are observed in cervical sagittal alignment.[15–24] The sagittal correction for subaxial cervical spine surgery with respect to age differences needs further study.

Therefore, we aimed to (i) analyze the variation trend with age of cervical sagittal alignment in asymptomatic volunteers retrospectively, (ii) evaluate clinical outcome of sagittal correction of subaxial cervical spine surgery further.

Methods

Data Sources and Participants

Asymptomatic volunteers and patients undergoing subaxial cervical spine surgery were enrolled and divided into six subgroups (20–29, 30–39, 40–49, 50–59, 60–69 and ≥70 groups).

This study was approved by the ethics committee (No: SYSEC-KY-KS-2021-219).

From October 2010 to November 2020, a total of 1223 asymptomatic volunteers were enrolled. All eligible candidates were (i) ≥20 years old, (ii) absence of neck pain, (iii) numbness and radiating pain of bilateral upper limbs, (iv) fatigue of bilateral lower extremities associated with cervical spine disease, and (v) a standard cervical lateral radiography taken during health examination. The exclusion criteria were as follows: (i) diagnosed with cervical spondylosis or any spinal disease, (ii) any mental illness. The number of each group: aged 20–29 (208 cases), aged 30–39 (238 cases), aged 40–49 (249 cases), aged 50–59 (255 cases), aged 60–69 (176 cases), and aged ≥70 (97 cases). The average age was 46.50 ± 15.2 years, and the male-to-female ratio was 631:592.

From June 2013 to December 2020, a total of 79 patients who underwent subaxial cervical spine surgery were enrolled. The inclusion criteria were (i) ≥20 years old, (ii) anterior and/or posterior approach of subaxial cervical fusion surgery, and (iii) complete medical records and imaging data. The exclusion criteria included (i) non-fusion surgery of the subaxial cervical spine, such as a simple cervical laminoplasty; (ii) atlantoaxial or occipito-cervical surgery, or thoracic, lumbar, pelvis and lower limbs surgery; and (iii) loss to follow-up. The number of each group: aged 20–29 (four patients), aged 30–39 (eight patients), aged 40–49 (19 patients), aged 50–59 (21 patients), aged 60–69 (21 patients), and aged ≥70 (six patients). The average age was 53.30 ± 12.96 years old. The average follow-up time was 11.89 ± 16.98 months.

Operative Management

The 79 patients underwent general anesthesia and subaxial cervical spine surgery. The surgeries were performed by one experienced surgeon. The procedures included one of the following, such as Anterior Cervical Discectomy and Fusion (ACDF), Anterior Cervical Corpectomy and Fusion (ACCF), Anterior Cervical Hybrid Decompression and Fusion (ACHDF); or posterior cervical laminectomy and fusion of bone grafting and internal fixation, laminoplasty combined with fusion of bone grafting and internal fixation, namely hybrid surgery; or combined surgery that refers to the combination of anterior cervical approach and posterior cervical approach.

Radiological Assessment

All the individuals enrolled were evaluated by cervical lateral radiography. The cervical sagittal parameters included C0-2 Cobb, C2-7 Cobb, C2-7 sagittal vertical axis (SVA), chin-brow vertical angle (CBVA), T1 slope (T1S), neck tilt (NT), and thoracic inlet angle (TIA).

The seven cervical sagittal parameters were measured as follows: C0-2 Cobb was measured as the angle between the lowest line of the anterior and posterior margin of the foramen magnum and the lower endplate of C2. C2-7 Cobb was measured as the angle between lower endplate of C2 and C7. C2-7 SVA was measured as the distance between a plumb line dropped from the center of C2 and the posterior superior aspect of C7. CBVA was measured as the angle subtended between a line drawn from the patient's chin to the brow and a vertical line. T1S was measured as the angle between the upper endplate of T1 and a horizontal line. NT was measured as the angle between a vertical line and a line that connected the midpoint of the upper endplate of T1 and the tip of the sternum. TIA was measured as the angle between a vertical line through the midpoint of the upper endplate of the T1 and a line that connected the tip of the sternum and the midpoint of the upper endplate of T1 (Figure 1).

Patients undergoing subaxial cervical spine surgery were evaluated preoperatively, postoperatively, and at the last follow-up. The regression equation of C2-7 Cobb was established and used to calculate the theoretical value of C2-7 Cobb in patients undergoing subaxial cervical spine surgery. Based on the normal cervical sagittal alignment, the correlation among loss, deviation value of C2-7 Cobb, and JOA recovery rate in patients undergoing subaxial cervical surgery was analyzed (Figure 2).

Clinical Outcome Measures

Recent outcome: The Japanese Orthopaedic Association (JOA) score was used to evaluate the neurological function of patients undergoing subaxial cervical spine surgery before and after surgery. The JOA score indicated the sensory, motor, and bladder functions of the patients. The total score of the JOA is 17, with a higher score reflecting a better condition. JOA recovery rate (%) = (postoperative JOA score − preoperative JOA score)÷(17 − preoperative JOA score) × 100.

Mid- and long-term outcome: Postoperative loss of C2-7 Cobb was used to evaluate the mid- and long-term change of cervical sagittal reconstruction in patients undergoing subaxial cervical spine surgery. The loss of C2-7 Cobb was the difference between postoperative C2-7 Cobb immediately and C2-7 Cobb of the last follow-up. The greater the loss, the worse the mid- and long-term outcome.

Statistical Analysis

Statistical analysis was performed using SPSS 25.0.

For asymptomatic volunteers, the seven cervical sagittal parameters were analyzed via univariate ANOVA test for age difference. Differences of the seven cervical sagittal parameters between the genders were examined with an unpaired t test. Continuous variables were shown as mean ± standard deviation. All continuous variables of patients and asymptomatic volunteers were homogeneous and normally distributed. The Pearson's correlation coefficient was determined between age and the seven cervical sagittal parameters (the correlation is none at an r of 0, poor at an r of 0.1–0.2, fair at an r of 0.3–0.5, moderate at an r of 0.6–0.7, very strong at an r of 0.8–0.9, and perfect at an r of 1).
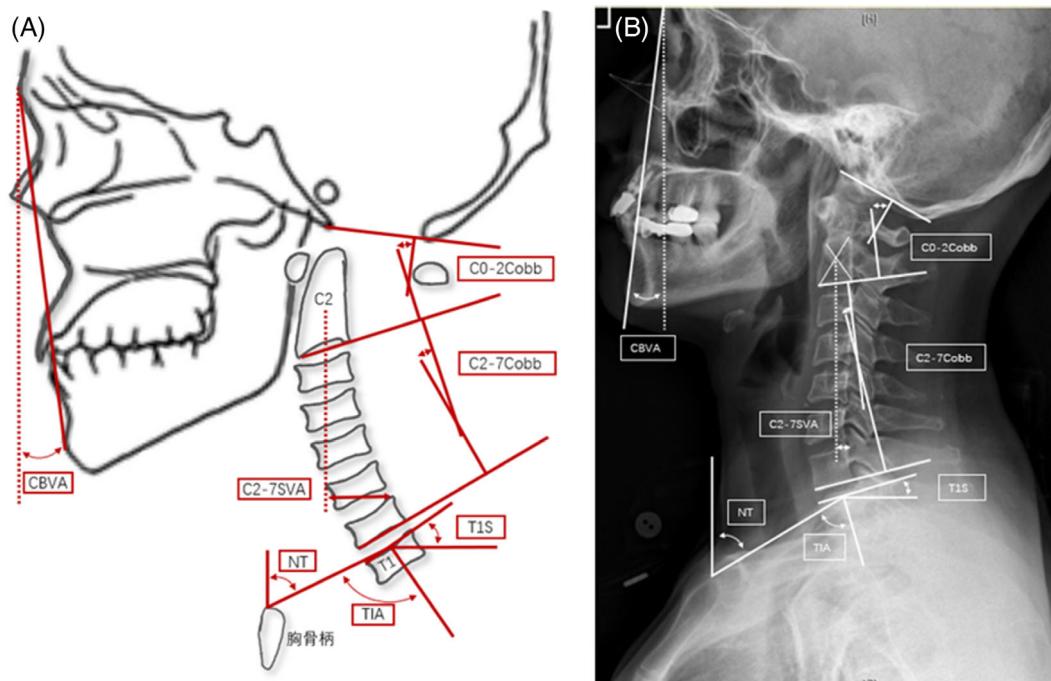

Fig. 1 Seven cervical sagittal parameters. (A) the sketch map. (B) The measured map
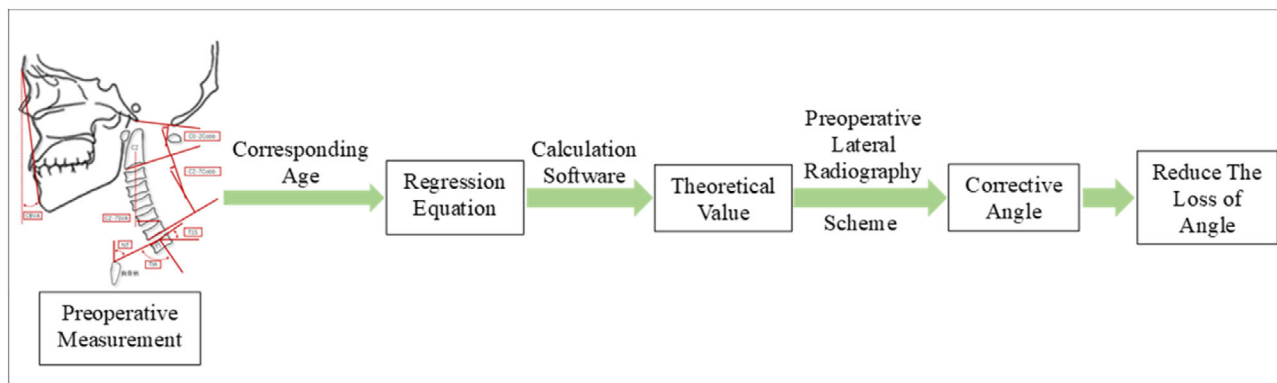
Fig. 2 Flowchart of preoperative scheme of C2-7 Cobb correction angle for subaxial cervical spine surgery

TABLE 1 Normal range of the seven cervical sagittal parameters for each age group (95% CI)							
	C0-2 Cobb	C2-7 Cobb	C2-7 SVA	CBVA	T1S	NT	TIA
20–29	15.89–53.18	−9.42–45.93	−7.01–35.50	−4.47–28.78	10.82–39.86	26.65–57.82	50.88–86.02
30–39	21.70–60.01	0.79–39.01	−5.36–30.60	1.20–27.71	12.49–40.00	26.30–61.81	50.93–86.53
40–49	17.03–55.53	−4.95–41.03	−7.16–33.02	−1.65–27.55	10.48–39.40	31.40–59.05	53.28–86.13
50–59	16.06–47.18	−1.96–44.58	−7.36–30.79	−2.72–24.58	12.20–41.52	34.32–60.90	56.40–89.94
60–69	15.55–59.65	1.11–42.79	−8.69–36.81	−3.95–29.45	11.21–42.19	30.97–64.33	55.27–95.72
≥70	11.40–50.11	−6.91–44.31	0.00–50.15	−3.95–31.43	11.80–44.73	30.74–63.65	54.64–104.93

Paired student's t test was used to analyze the difference of JOA score preoperative and postoperative in 79 patients. Theoretical value of C2-7 Cobb was calculated based on the regression equation of C2-7 Cobb obtained from asymptomatic volunteers. Then, the deviation value, loss value of C2-7 Cobb were determined as follows,

the deviation value = postoperative value-theoretical value (1)
the loss value = postoperative value-the last follow-up value (1, 2)

The Pearson's correlation coefficient was determined among the deviation value, loss value of C2-7 Cobb, and JOA recovery rate. $p < 0.05$ was considered statistically significant.

Results

The cervical sagittal alignment in asymptomatic volunteers:

Age Difference

Age differences were observed in the seven cervical sagittal parameters of asymptomatic volunteers ($p < 0.05$) (Tables 1 and 2). The C0-2 Cobb decreased gradually with increasing age. The C2-7 Cobb, C2-7 SVA, T1S, NT, and TIA increased gradually with increasing age. The CBVA fluctuated with increasing age (Figure 3).

Gender Difference

No difference of C2-7 SVA and CBVA was observed between males and females ($p > 0.05$). But the C0-2 Cobb was smaller in males than in females, and C2-7 Cobb, TIS, NT, and TIA were larger in males than in females ($p < 0.05$) (Figure 4).

Correlation Strength

The T1S demonstrated a moderate correlation with C2-7 Cobb ($r = 0.60$, $p < 0.01$); C0-2 Cobb, C2-7 SVA, CBVA, and TIA demonstrated a fair correlation with C2-7 Cobb ($r = -0.30, -0.33, 0.41, 0.40$, $p < 0.01$); age demonstrated a poor correlation with C2-7 Cobb ($r = 0.19$, $p < 0.01$) (Table 3). The regression equations were established of C2-7 Cobb with C0-2 Cobb, C2-7 SVA, CBVA, and T1S of each age group (Table 4).

The outcome of the patients with subaxial cervical spine surgery are as follows.

Recent Outcome

For the patients undergoing subaxial cervical spine surgery, the JOA score improved after surgery (pre-operation 12.10 ± 3.48 vs post-operation 13.30 ± 3.46). And the JOA recovery rate $31.85 \pm 29.90\%$. The decompression was sufficient, and the neurological function recovered. The reconstruction of cervical spine stability was satisfied, and all

SUBAXIAL CERVICAL SAGITTAL CORRECTION

| TABLE 2 Age distribution of the seven cervical sagittal parameters (mean ± standard deviation)						
	C0-2 Cobb	C2-7 Cobb	C2-7 SVA	CBVA	T1S	NT	TIA
20–29	34.24 ± 9.18	15.25 ± 12.83	12.83 ± 10.36	9.40 ± 8.46	25.06 ± 6.87	43.10 ± 7.51	68.39 ± 9.01
30–39	41.10 ± 9.42	17.07 ± 10.53	11.44 ± 9.15	12.00 ± 6.58	24.66 ± 6.51	43.38 ± 8.45	68.09 ± 9.34
40–49	36.19 ± 9.55	18.28 ± 12.58	12.05 ± 10.15	10.99 ± 7.69	25.69 ± 7.21	44.46 ± 6.80	70.32 ± 8.88
50–59	31.81 ± 8.16	19.63 ± 11.38	12.85 ± 9.85	9.82 ± 6.64	26.80 ± 7.30	47.01 ± 6.66	73.78 ± 9.78
60–69	35.56 ± 11.37	22.32 ± 11.10	13.37 ± 11.24	12.46 ± 8.14	28.25 ± 7.46	46.97 ± 8.43	75.56 ± 9.36
≥70	29.35 ± 9.08	21.70 ± 13.39	18.01 ± 11.54	12.56 ± 9.06	27.50 ± 8.44	48.98 ± 8.63	75.98 ± 11.77
p value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
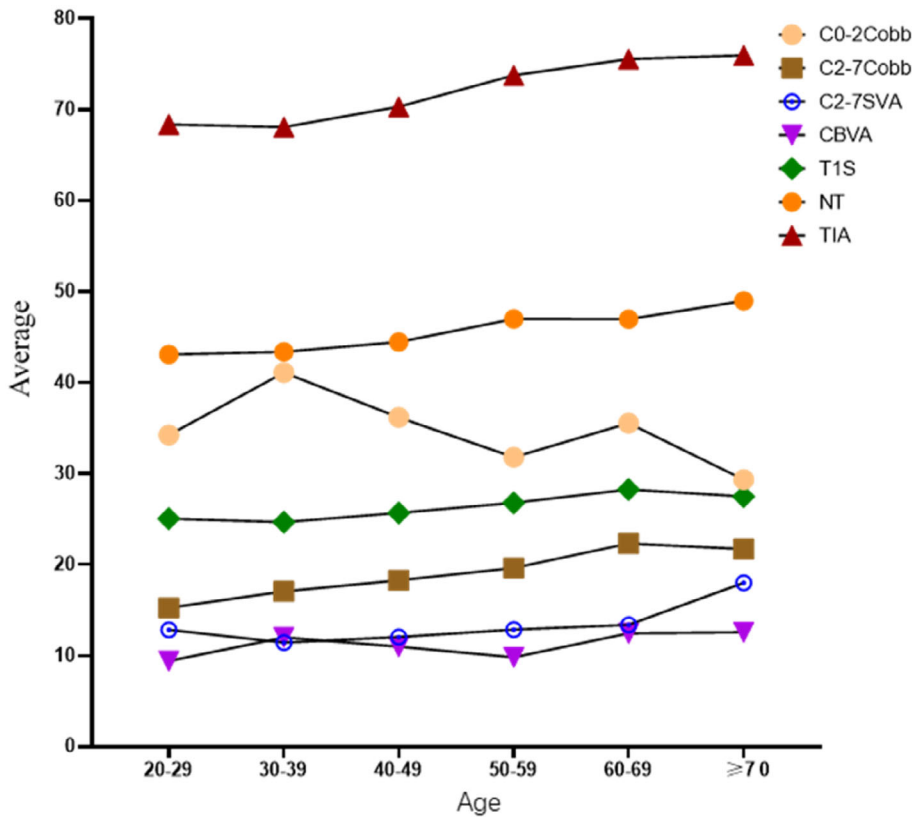
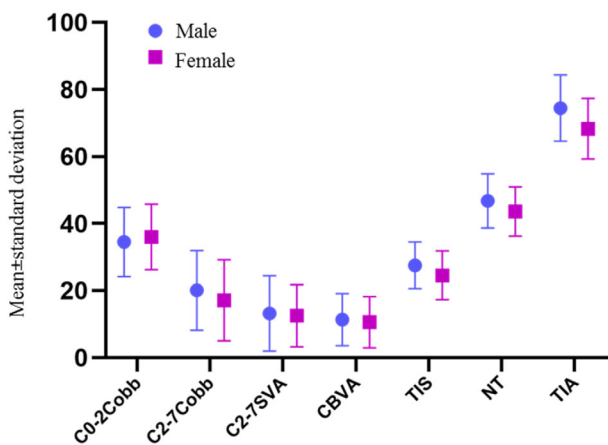Fig. 3 The trend of the seven cervical sagittal parameters with age

Fig. 4 Gender differences in the seven cervical sagittal parameters

79 patients had no complications related to internal fixation, such as loosening of internal fixation and broken screws.

Mid- and Long-Term Outcome

In the 79 patients, the preoperative C2-7 Cobb and T1S first increased and then decreased with age, while C0-2 Cobb, C2-7 SVA, and CBVA fluctuated within a certain range with age (Figure 5A). The loss of C2-7 Cobb demonstrated a moderate correlation with deviation of C2-7 Cobb ($r = 0.33$, $p < 0.01$). The JOA recovery rate demonstrated no correlation with deviation of C2-7 Cobb ($r = 0.081$, $p = 0.48$) (Figure 5B,C). Then a regression equation was determined as *loss of C2-7 Cobb = −0.64 + 0.26 × deviation of C2-7 Cobb*. According to the regression equation, when the deviation of C2-7 Cobb was +2.46°, the loss of C2-7 Cobb was 0°, and

TABLE 3 The Pearson's correlation coefficient (r) of the eight variables in asymptomatic volunteers

	C0-2 Cobb	C2-7 Cobb	C2-7 SVA	CBVA	T1S	NT	TIA	Age
C0-2 Cobb	-	−0.30**	0.24**	0.25**	−0.05	−0.04	−0.06*	−0.19**
C2-7 Cobb	-	-	−0.33**	0.41**	0.60**	−0.04	0.4**	0.19**
C2-7 SVA	-	-	-	−0.42**	0.20**	0.00	0.15**	0.12**
CBVA	-	-	-	-	0.05	0.10**	0.12**	0.06*
T1S	-	-	-	-	-	−0.15**	0.61**	0.17**
NT	-	-	-	-	-	-	0.65**	0.24**
TIA	-	-	-	-	-	-	-	0.30**
Age	-	-	-	-	-	-	-	-

$*p < 0.05.; **p < 0.01.$

TABLE 4 The regression equations of C2-7 Cobb

Age groups	Regression equations
20–29	$Y = -0.097 - 0.427*X_1 - 0.269*X_2 + 0.629*X_3 + 1.097*X_4$
30–39	$Y = 4.494 - 0.313*X_1 - 0.265*X_2 + 0.566*X_3 + 0.879*X_4$
40–49	$Y = 5.029 - 0.508*X_1 - 0.204*X_2 + 0.687*X_3 + 1.033*X_4$
50–59	$Y = 2.646 - 0.437*X_1 - 0.160*X_2 + 0.626*X_3 + 1.000*X_4$
60–69	$Y = 3.875 - 0.209*X_1 - 0.381*X_2 + 0.307*X_3 + 0.962*X_4$
≥70	$Y = 9.497 - 0.516*X_1 - 0.429*X_2 + 0.394*X_3 + 1.096*X_4$

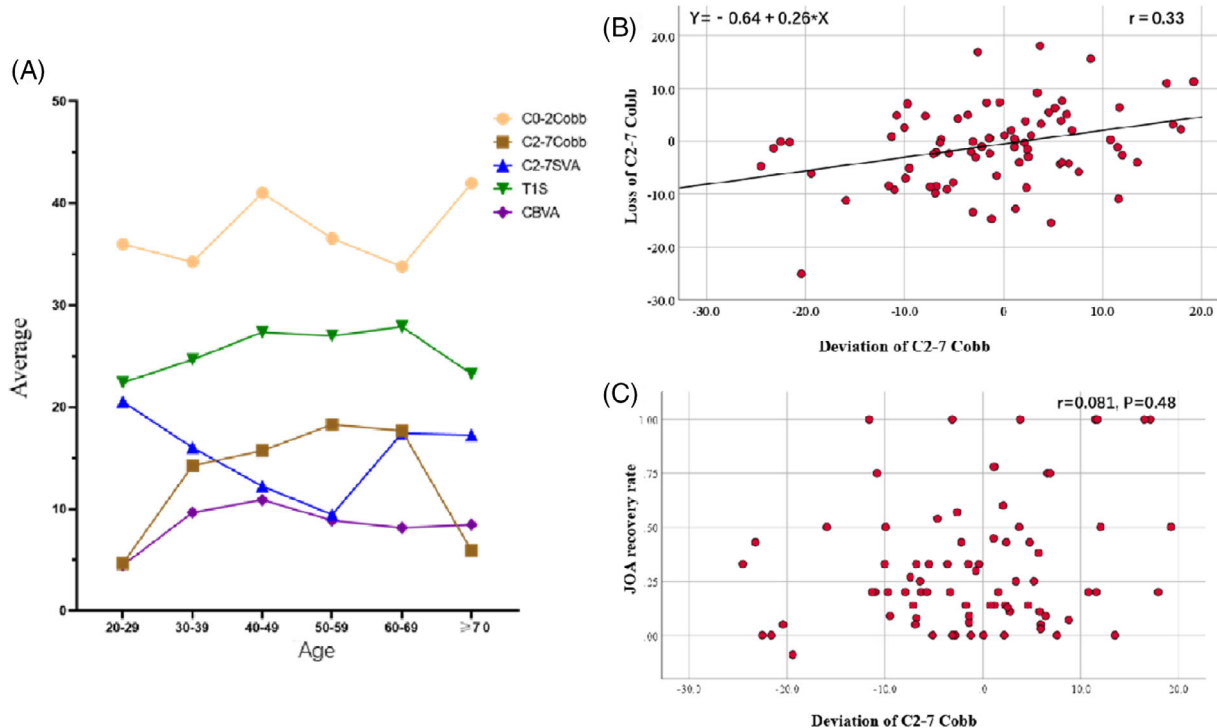Notes: Y = C2-7 Cobb; X_1 = C0-2 Cobb; X_2 = C2-7 SVA; X_3 = CBVA; X_4 = T1S.

Fig. 5 Age distribution and correlation of the cervical sagittal parameters in 79 patients. (A) The variation trend of the five cervical sagittal parameters with age in 79 patients; (B, C) Correlation coefficient of deviation value, loss value of C2-7 Cobb, and JOA recovery rate
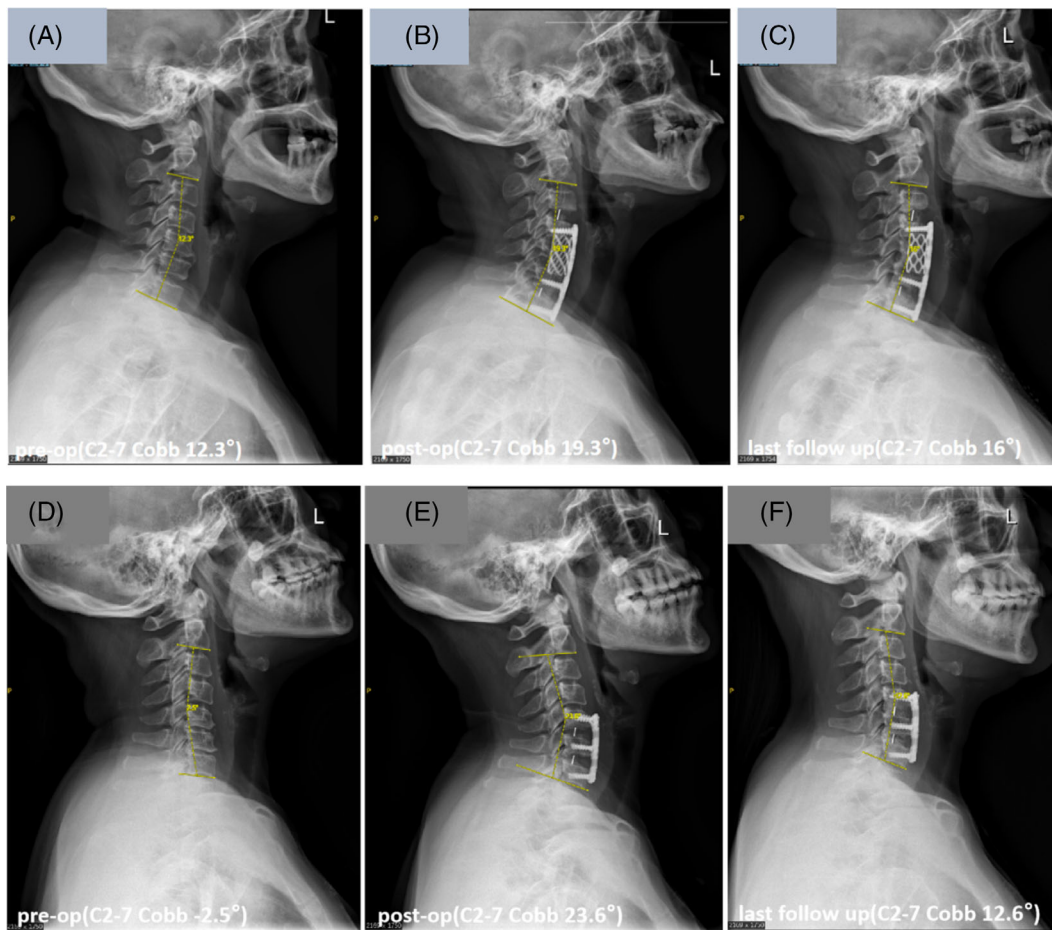
Fig. 6 The two cases illustrate this result. (A-C) A 63-year-old female patient, followed up for 54 months, underwent a C3-7 ACHDFs with a C2-7 Cobb deviation of 3.8° and a C2-7 Cobb loss of 3.3°. And the JOA score improved (pre-op 15 vs post-op 17). (D-F) A 56-year-old female patient, followed up for 22 months, underwent a C5-7 ACDFs with a C2-7 Cobb deviation of 16.5° and a C2-7 Cobb loss of 11.0°. And the JOA score improved (pre-op 15 vs post-op 17)

the postoperative cervical curvature was well-maintained (Figure 6).

Discussion

In this study, we found that the age difference of cervical sagittal alignment was obvious, and the C2-7 Cobb increased with age especially. And the loss value of C2-7 Cobb was positively correlated with the deviation to the theoretical value based on the calculated theoretical value.

The Variation Trend with Age of Cervical Sagittal Alignment in Asymptomatic Volunteers

Located on the top of the spine, the cervical spine alignment had obvious age differences. Currently, there were three different views: no age difference in subaxial cervical lordosis angle (C2-7 Cobb),[22] decreasing with age,[17] or increasing with age.[15,18,19,23–25] And the prevailing view supported the latter. Yukawa et al. retroactively analyzed the cervical sagittal parameters of 1230 healthy volunteers by cervical lateral

radiography and found that the C2-7 Cobb increased with age.[24] In this study, the age and gender differences were found in the cervical sagittal alignment of normal people. And the C2-7 Cobb increased with age, in accordance with the results of most of the current research. With the increase of age, the anterior tilt of pelvis increased, lumbar lordosis decreased, thoracic kyphosis increased, and the spine showed a big "C" type kyphosis trend. However, the cervical vertebra, located at the upper segment of the spine, was not only supposed to coordinate the balance with the thoracic vertebra, lumbar vertebra, and pelvis but also to maintain the horizontal gaze. Therefore, the cervical vertebra needed greater lordosis to maintain the horizontal gaze, showing a compensatory change in the opposite direction to the thoracic and lumbar vertebra.

The seven cervical sagittal parameters, including upper cervical lordosis angle (C0-2 Cobb), subaxial cervical lordosis angle (C2-7 Cobb), cervical sagittal vertical axis (C2-7 SVA), chin-brow vertical angle (CBVA), and cervical pedestal

parameters (T1S, NT and TIA), are often used to evaluate cervical sagittal balance.[11] Cervical spine is a whole alignment, in order to maintain the horizontal gaze, a certain linkage relationship exists between each other of the cervical sagittal parameters. Previous studies have confirmed that C2-7 Cobb is associated with T1S, C0-2 Cobb, TIA, and C2-7 SVA, and T1S had the strongest correlation with C2-7 Cobb.[17,18,25–28] In this study, we found that C2-7 Cobb was correlated with the five parameters other than NT, and T1S had the greatest influence on C2-7 Cobb, which was consistent with previous studies. However, the effect of the CBVA deviation, with an acceptable range of $-1.5°$ to $5.8°$, on cervical curvature has been confirmed.[29] So, the CBVA were included in this study. We established the multiple linear regression equations of C2-7 Cobb with C0-2 Cobb, C2-7 SVA, CBVA, and T1S based on age difference further.

The Sagittal Correction of Subaxial Cervical Spine Surgery

At present, the standard of sagittal correction for subaxial cervical spine surgery has not been uniform.[11] It's defined in different ways, like local angle, cervical curvature, and cervical relative offset position, and is not easy to grasp in practice.[1,3,12–14] But distinct age differences have been observed in cervical sagittal alignment, and it is one of the key risk factors influencing the cervical sagittal alignment.[15–24] So, we propose a reconstruction algorithm for cervical sagittal alignment based on age difference. In this study, we established a regression equation based on age difference, calculated a theoretical value of C2-7 Cobb, and confirmed that the loss of correction angle of C2-7 Cobb was positively correlated with the deviation value. When the deviation value of C2-7 Cobb was closer to $+2.46°$, the loss of C2-7 Cobb tended to be $0°$. In other words, the postoperative C2-7 Cobb was slightly greater than the theoretical C2-7 Cobb value of the corresponding age, the postoperative cervical curvature would be better maintained (Figure 6). This perspective has not been reported previously. Therefore, it could provide a reference for subaxial cervical sagittal correction based on age difference. This algorithm was convenient and suitable for promotion.

Limitations

However, there were some limitations in this study. This study was a retrospective study. The sample capacity of the second part was small, and there was a certain selection bias. There is a need to analyze the risk factors with the clinical symptoms and work circumstance in further studies. We focused on the cervical spine mainly and no full-spine evaluation was performed. The clinical significance of loss of correction angle needed further studies.

Conclusion

The age difference of cervical sagittal alignment was obvious, and the C2-7 Cobb increased with age. Under the premise of complete decompression and ideal stability reconstruction in subaxial cervical spine surgery, the closer the correction of C2-7 Cobb was to the theoretical value of corresponding age, the smaller the loss of correction angle was, and the better the maintenance of cervical curvature was. Therefore, personalized sagittal correction should be performed according to age difference for subaxial cervical spine surgery.

Author Contributions

WJL—acquisition of data, analysis and interpretation of data drafting of the manuscript, critical revision of the manuscript; GR—acquisition of data, analysis and interpretation of data, critical revision of the manuscript; YCC—conception and design, analysis and interpretation of data, acquisition of data, critical revision of the manuscript; YHL—conception and design, analysis and interpretation of data, acquisition of data, critical revision of the manuscript; WZY, CZP, PXS, ZD, JX and ZQC—acquisition of data; LB, HXM and GLB—critical revision of the manuscript. All authors read and approved the final manuscript. All authors listed meet the authorship criteria according to the latest guidelines of the International Committee of Medical Journal Editors, and all authors are in agreement with the manuscript.

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