Original Article

Postoperative C-reactive protein levels correlate with reduced spinal column mobility after median sternotomy: a prospective cohort study

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Background: The sternum is connected to the spinal column via the ribs, forming the thorax. Therefore, it is necessary to consider the effect of a midline sternotomy on the spinal column, but no *in vivo* studies have been conducted to date. We investigated the changes in the range of motion of the spinal column before and after midline sternotomy and the perioperative factors that have the greatest influence.

Methods: The participants were patients who had undergone cardiac surgery through a standby midline sternotomy. Spinal range of motion in forward flexion was measured before and after surgery. The following perioperative factors were investigated: operating time, days to postoperative measurement, C-reactive protein (CRP) measurement on the third postoperative day, the day of the start of bed release, and the stage of bed release progression on the second postoperative day. Statistics were compared between the two groups before and after surgery for each factor. Multiple regression analysis (forced entry method) was then performed with the change in spinal range of motion, which showed statistical differences between the preoperative and postoperative groups, as the dependent variable and each perioperative factor as the independent variable.

Results: The study included 93 patients. Postoperatively, there was a significant decrease in thoracic spine range of motion. Multiple regression analysis showed that an increase in CRP on the third postoperative day was responsible for the decrease in thoracic range of motion ($\beta=-0.30$, $P<0.01$).

Conclusions: After median sternotomy, thoracic spine range of motion was decreased and correlated with postoperative inflammation.

Keywords: Median sternotomy; spine; perioperative; C-reactive protein (CRP); multiple regression analysis

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Introduction

Background

In Japan, the number of cardiac surgeries is on the rise due to the high incidence of cardiovascular diseases (1). The indications for cardiac surgery are expanding due to the aging population, technological advances, aggressive surgical intervention, and advances in postoperative management. The number of cardiac operations surveyed by the Japanese Society of Cardiology increased from 72,572 for a population of 126,706 million in 2017 to 73,294 for a population of 125,502 million in 2021 (2). Median sternotomy is often used as a technique during cardiac surgery; the sternum is incised longitudinally and opened using a sternal spreader to secure the surgical field of view. Postoperatively, the sternum is fixed with thread, wire, or a sternal plate.

The sternum, together with the thoracic vertebrae and ribs, forms the thoracic cage, which is connected by the costovertebral and sternocostal joints consisting of the transverse costovertebral and costovertebral head joints. The thoracic cage contributes to the stability of the thoracic spine (3) and is a stronger and more stable structure than the cervical and lumbar spine. Median sternotomy is predicted to disrupt this thoracic structure, causing dysfunction of the spinal column.

Generally, changes in spinal alignment and range of motion cause decreased respiratory function (4,5); strength reduction in the trunk flexor, trunk extensor, and thoracic flexor muscles (6); and decreased grip strength (7). This reduces mobility (8) and balance (9), leading to falls and necessitating interventions to limit or reverse the changes in spinal alignment. However, after a median sternotomy, interventions on the spine are restricted for approximately 3 months until bony fusion of the sternum is achieved; trunk rotation, upper limb movements, and carrying heavy objects may cause displacement of the sternotomy site (10).

Highlight box

Key findings
- Spinal range of motion showed a decrease in thoracic spine range of motion after median sternotomy. Perioperative factors involved in decreased range of motion were indicated by C-reactive protein measurements on postoperative day 3.

What is known and what is new?
- The only studies investigating the effects of a median sternotomy on the spine reported results in thoracic spine specimens.
- Therefore, *in vivo* results may be different and were investigated in this study. Perioperative related factors were also investigated.

What is the implication, and what should change now?
- Appropriate rehabilitation to improve decreased range of motion and interventions to reduce postoperative inflammation are needed.

Rationale and knowledge gap

Although studies on postoperative changes in the spine due to other surgical methods have been reported *in vivo* (11), the only studies that have examined the effects of a mid-thoracic incision on the spine have used thoracic spine specimens (12-14). Therefore, the range of motion *in vivo*, including soft tissues and surrounding muscles, has not been examined. Furthermore, the effects of postoperative inflammation (15) and rehabilitation (16), which are known to cause perioperative complications and changes in physical function, have not been examined.

Objective

It is important to investigate the post-median sternotomy changes in the range of motion of the spine *in vivo*. This study aimed to compare the range of motion of the spine before and after cardiac surgery through a median sternotomy and investigate the effects of perioperative biological reactions and rehabilitation on the spine. We present this article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1439/rc).

Methods

Study design and population

We carried out a prospective cohort study. Participants were recruited from the Department of Cardiac Surgery, International University of Health and Welfare Hospital from April 2017 to March 2021. Inclusion criteria were as follows: age ≥18 years and having undergone cardiac surgery through a median sternal incision on a standby basis. Patients with a history of neurological or spinal disease, those who had difficulty holding a standing or forward-bent position due to cognitive decline or complications, and those with missing data were excluded. The sample size was determined assuming that multiple regression analysis would be performed. Assuming an effect size f^2=0.15, α=0.05, 1 – β=0.8, and number of predictors =8, a sample of 109 was required.

Subsequently, assuming that 10–20% of the total sample would be excluded, the number of participants was set at 130.

This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the ethical committee of the International University of Health and Welfare (approval No. 17-Io-138). Participants were informed of the content and purpose of the study in advance, and their verbal and written informed consents were obtained.

Measurements

Basic information on the participants, including age, sex, height, weight, body mass index (BMI), indication for surgery, New York Heart Association classification, complications, and preoperative activities of daily living BMI status, was obtained from medical records.

Spinal motion measurement

Spinal range of motion was measured using the Spinal Mouse (Idiag, Volkerswill, Switzerland) device in a noninvasive, reliable, and reproducible way. This device's measurements have been shown to correlate with X-rays (17,18). The standard error of measurement varies from 0.61 to 13.18 degrees, depending on the area of interest (17-19). Measurements were taken preoperatively, up to 1 week before surgery, and postoperatively, before discharge. The measurement positions were at rest in a standing position and the trunk forward-bending position. In each position, both feet were parallel to each other, with a foot width of 10 cm between the medial phalanges, and both upper limbs were in a naturally drooping position. In the upright position, the head was kept gazing forward at eye level, and the trunk was in forward-bending and backward-bending positions, sequentially; the head was kept in the middle position between forward and backward bending. The trunk forward-bending was performed at maximum effort. By tracing the paraspinal area from the seventh cervical vertebra to the third sacral vertebra, the sacral range of motion, lumbar range of motion, thoracic range of motion, and overall tilt range of motion were measured from the upright position to the trunk forward-bending position.

Perioperative information

Perioperative information on the procedure, sternal fixation method, operative time, intraoperative blood loss, and C-reactive protein (CRP) on the third postoperative day were extracted from the medical records. The postoperative elevation of CRP (postoperative day 3) is a representative laboratory value that indicates the degree of systemic inflammatory response. Inflammation has been reported to cause functional symptoms due to inflammatory pain, edema and swelling, and is associated with postoperative complications.

The following sternal fixation methods were used after sternotomy: Ethibond Excel thread (Johnson & Johnson, New Brunswick, NJ, USA) (20), Yokozuna Wire (Matsuda Medical Industries, Tokyo, Japan) (21), Grand Fix sternal pin (Gunze, Tokyo, Japan) (22), SternaLock sternal plate (BIOMET, Warsaw, IN, USA) (23), and Super Fixove MX mesh plate (Teijin Medical Technologies, Osaka, Japan) (24).

Perioperative rehabilitation

After evaluation of physical function and consultation with the attending physician, exercise therapy to maintain physical function in accordance with cardiac function and respiratory training to prevent postoperative complications were commenced preoperatively. Postoperatively, patients began early mobilization following consultation with the attending physician 1 day after surgery. The starting of mobilization, the rehabilitation schedule, and exercise loading were performed under the supervision of a physical therapist in accordance with the Guidelines for Rehabilitation in Cardiovascular Disease (25). Rehabilitation progressed with interventions aimed at achieving independence on the ward within 4 to 5 days of commencing mobilization.

The date and stage of postoperative mobilization were investigated. The date was defined as the date when the head of the bed was first elevated. A numerical value was assigned to each stage of progression as follows: 1: bed rest, 2: elevation of the head of the bed, 3: end-sitting, 4: standing, 5: stepping, 6: indoor walking, 7: 50 m walking, and 8: 100 m walking. The numerical value achieved on postoperative day 2 was recorded.

Statistical analysis

The normality of each variable was checked with the

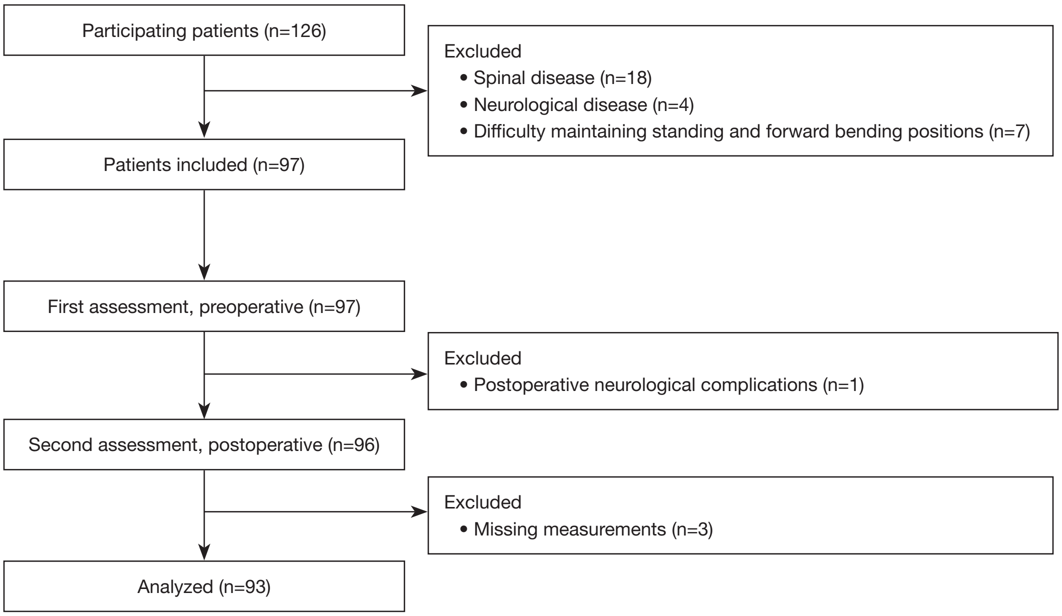

Figure 1 Flow-chart of patient recruitment for this study.

Kolmogorov-Smirnov test. The paired *t*-test was used for normally distributed variables before and after surgery for each factor, and the Wilcoxon signed-rank test for non-normally distributed variables. Multiple regression analysis (forced entry method) was then performed using the amount of change in spinal range of motion as the dependent variable; surgery time, CRP on the third postoperative day, the start of postoperative weaning, and the weaning stage on the second postoperative day as perioperative factors, and age, sex, BMI, and days until postoperative measurement as adjustment variables. Multicollinearity was checked using the variance inflation factor (VIF) and normality of residuals using the Shapiro-Wilk test. Statistical tests were performed using the statistical analysis software SPSS 25 (IBM Corp., Armonk, NY, USA). As an a posteriori test, G Power was used to test for effect size and power. In addition, as a subanalysis, a correlation analysis was performed between the amount of change in spinal range of motion and sex and the factors that showed a significant relationship in the multiple regression analysis. Spearman's rank correlation coefficient was used for correlation analysis. The probability of significance was set at 5%.

Results

There were 126 participants in the study. After excluding 33 participants who met the exclusion criteria (18 with spinal disease, four with neurological disease, seven with difficulty maintaining standing and forward bending positions, one with postoperative neurological complications, and three with missing measurements), 93 participants (60 males and 33 females; age: 66.1±11.6 years; height: 161.4±9.4 cm; weight: 56.9±10.5 kg; BMI: 21.8±3.1 kg/ m^2) were included in the analysis (*Figure 1*). The basic attributes of the analyzed participants are shown in *Table 1*. Differences were observed between men and women in the number of comorbidities, surgical procedures, and sternal fixation methods.

Pre- and postoperative spinal range of motion is shown in *Table 2*. Thoracic spine range of motion was 13.7°±14.3° preoperatively and 8.8°±15.6° postoperatively, showing a significant decrease after surgery ($P<0.05$; $r=0.40$; $1-\beta=0.96$). There were no significant differences in sacral range of motion, lumbar spine range of motion, or overall tilt range of motion.

The results of multiple regression analysis with thoracic range of motion as the dependent variable are shown in *Table 3*. Multiple regression analysis showed that an increase in CRP on the third postoperative day was responsible for the decrease in thoracic range of motion ($\beta=-0.30$; $P<0.01$). VIF was all less than 10, showing no multi-collinearity, and the Durbin-Watson ratio was 1.962. The Shapiro-Wilk test was performed on the residuals, and the result was 0.74, confirming normality.

Table 1 Participant characteristics

Variables	Total (n=93)	Male (n=60)	Female (n=33)	P value
Age (years)	66.1±11.6	64.5±12.8	69.1±8.4	n.s
BMI (kg/m^2)	21.8±3.1	22.2±3.0	21.0±3.2	n.s
Preoperative				
Disease state				
Aortic valve stenosis	18 [19]	12 [20]	6 [18]	n.s
Aortic regurgitation	24 [26]	16 [27]	8 [24]	n.s
Mitral valve stenosis	2 [2]	0 [0]	2 [6]	n.s
Mitral regurgitation	44 [47]	22 [37]	22 [67]	<0.05†
Tricuspid regurgitation	29 [31]	10 [17]	19 [58]	<0.05†
Coronary artery disease	25 [27]	18 [30]	7 [21]	n.s
Atrial fibrillation	28 [30]	15 [25]	13 [39]	n.s
Thoracic aortic aneurysm	2 [2]	2 [3]	0 [0]	n.s
Hypertrophic cardiomyopathy	2 [2]	1 [2]	1 [3]	n.s
Cardiac myxoma	1 [1]	0 [0]	1 [3]	n.s
Ventricular aneurysm	1 [1]	1 [2]	0 [0]	n.s
Ventricular septal defect	1 [1]	0 [0]	1 [3]	n.s
Atrial septal defect	1 [1]	0 [0]	1 [3]	n.s
Constrictive pericarditis	1 [1]	1 [2]	0 [0]	n.s
Patent foramen ovale	1 [1]	0 [0]	1 [3]	n.s
Prosthetic valve infection	1 [1]	1 [2]	0 [0]	n.s
High blood pressure	75 [81]	50 [83]	25 [76]	n.s
Hyperlipidemia	25 [27]	16 [27]	9 [27]	n.s
Diabetes	25 [27]	15 [25]	10 [30]	n.s
Kidney failure	14 [15]	7 [12]	7 [21]	n.s
New York Heart Association				
I	17 [18]	14 [23]	3 [9]	n.s
II	61 [66]	37 [62]	24 [73]	n.s
III	12 [13]	6 [10]	6 [18]	n.s
IV	3 [3]	3 [5]	0 [0]	n.s
Activities of daily living state				
Independence	93 [100]	60 [100]	33 [100]	n.s
Postoperative				
Type of cardiac surgery				
Aortic valve replacement	42 [45]	28 [47]	14 [42]	n.s
Mitral valve replacement	19 [20]	6 [10]	13 [39]	<0.05†

Table 1 (*continued*)

Table 1 (*continued*)

Variables	Total (n=93)	Male (n=60)	Female (n=33)	P value
Mitral valvuloplasty	26 [28]	16 [27]	10 [30]	n.s
Tricuspid annuloplasty	32 [34]	12 [20]	20 [61]	<0.05†
Coronary artery bypass surgery	25 [27]	16 [27]	9 [27]	n.s
Maze	11 [12]	5 [8]	6 [18]	n.s
Pulmonary vein isolation	20 [22]	11 [18]	9 [27]	n.s
Morrow	3 [3]	2 [3]	1 [3]	n.s
Tumor resection	2 [2]	1 [2]	1 [3]	n.s
Patent foramen ovale closure	2 [2]	2 [3]	0 [0]	n.s
Total arch replacement	1 [1]	0 [0]	1 [3]	n.s
Ventricular septal defect closure	1 [1]	0 [0]	1 [3]	n.s
Sternum fixation method				
String	13 [14]	6 [10]	7 [21]	n.s
Wire	81 [87]	55 [92]	26 [79]	n.s
Sternal pin	15 [16]	5 [8]	10 [30]	<0.05†
Sternal plate	70 [75]	48 [80]	22 [67]	n.s

Data are presented as n [%] or mean ± SD. Some overlap in disease state, type of cardiac surgery, and sternal fixation method. †, chi-squared test. n.s, not significant; BMI, body mass index; SD, standard deviation.

Table 2 Comparative results of preoperative and postoperative spinal range of motion

Upright position-trunk forward bending position	Preoperative	Postoperative	P value
Sacral range of motion (°)	55.3±20.2	56.7±19.3	0.39
Thoracic spine range of motion (°)	13.7±14.3	8.8±15.6	<0.01
Lumbar spine range of motion (°)	39.3±14.5	39.2±13.6	0.82
Overall tilt range of motion (°)	90.8±23.8	91.6±22.4	0.63

Data are presented as mean ± SD. SD, standard deviation.

In the sub-analysis, correlation analysis was performed between the change in thoracic spine range of motion and CRP on postoperative day 3 (5.9±3.5 mg/dL for men and 6.0±4.1 mg/dL for women; *Figure 2*). The results showed that women were more likely to have a decreased range of thoracic spine motion with higher CRP on postoperative day 3 compared to men.

Discussion

Key findings

This study was conducted on patients who underwent cardiac surgery through a median sternotomy with the aim of analyzing pre- and postoperative changes in spinal range of motion and the factors contributing to these changes. Comparison of pre- and postoperative spinal range of motion showed a decrease in thoracic spine range of motion postoperatively. Perioperative factors involved in the reduced thoracic spine range of motion were examined, demonstrating a correlation with postoperative day 3 CRP measurements. The elevated CRP may be associated with a reduction in thoracic spine range of motion due to edema around the wound and thoracic area.

Table 3 Results of multiple regression analyses examining the effect of the perioperative period on the spine

Variables	Partial regression coefficient	Standard partial regression coefficient	P value	R^2
Constant	29.03	–	–	–
Age	–0.04	0.12	0.72	–
Sex	–2.15	2.88	0.46	–
BMI	–0.69	0.42	0.11	–
Days to postoperative measurement	–0.25	0.21	0.24	–
Surgery duration	–0.01	0.01	0.62	–
Start date of getting out of bed	1.39	1.98	0.49	–
Weaning phase on the second postoperative day	–0.47	1.14	0.68	–
CRP on postoperative day 3	–0.94	0.41	0.02	–
Durbin-Watson: 1.96	–	–	–	0.15

BMI, body mass index; CRP, C-reactive protein.

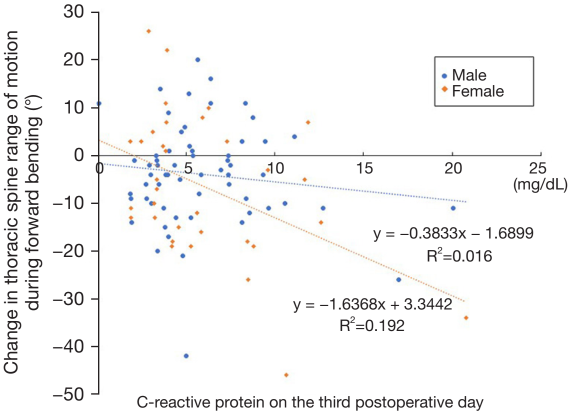

Figure 2 Relationship between thoracic spine range of motion change during forward bending and CRP on the third postoperative day by sex. CRP, C-reactive protein.

Spine range of motion

Mannen *et al.* (12) and Brasiliense *et al.* (13) previously used thoracic specimens to investigate changes to spinal range of motion during sternotomy and reported an increase in thoracic spine range of motion due to disruption of thoracic cage stability. In addition, Liebsch *et al.* (14) investigated thoracic spine range of motion before sternal manipulation, after median sternotomy, and after sternal wire fastening. They reported that thoracic stability improved after wire fastening compared to that after median sternotomy, and thoracic spine hypermobility was reduced; however, it did not return to baseline. In the present study, only thoracic spine range of motion was significantly decreased postoperatively, a result that differed from previous studies using thoracic specimens. Thoracic spine specimens may not reflect actual range of motion because surrounding muscles and soft tissues are excluded. It is possible that perioperative biological reactions, which have not yet been analyzed, may be influencing the results.

Range of motion changes and perioperative factors

A factor analysis of several perioperative factors revealed that the decreased thoracic spine range of motion was associated with a higher CRP on the third postoperative day, indicating that the degree of inflammation was important. CRP is a type of acute phase protein which is synthesized in the liver and released into the blood when inflammation or tissue destruction occurs. The postoperative rise in CRP could be interpreted as an immune response to prevent cellular damage and destroy pathogens that may have infiltrated the body during the surgical intervention. CRP is widely used in clinical practice as an inflammatory marker and begins to rise within a few hours of surgery, reaching a maximum value between 48 and 72 hours postoperatively. Therefore, an elevated CRP on the third postoperative day is a useful predictor of increased postoperative complications and poor prognosis (26,27). There are multiple possible mechanisms for the correlation between elevated CRP 3 days postoperatively and the thoracic kyphosis angle change in the postoperative forward-bending position. The first mechanism is enhanced and prolonged edema. During inflammation, chemical transmitters such as histamine and serotonin released from mast cells and other substances cause vasodilation and increased vascular permeability, leading to edema (28). Since the participants in this study underwent cardiac surgery, their circulatory function was already impaired (29), further prolonging any edema. Edema is one factor affecting joint range of motion (30). Since the sternotomy surgical site was located on the anterior aspect of the chest, it is possible that localized inflammatory edema around the wound limited thoracic spine movement in the trunk forward-bending position. Second, the higher the inflammatory marker value, the more likely that scarring will progress (31). Scarring of the surgical wound may have reduced thoracic cage movement due to the reduced mobility of the soft tissue around the wound. Third, muscle weakness due to protein catabolism may have occurred. The higher the inflammatory marker level, the higher the protein catabolism, and the more likely that postoperative muscle weakness will occur (32). Thoracic spine mobility requires pelvic fixation and control by the muscles connecting the pelvis and thoracic spine (33); protein catabolism may have affected these muscles.

We performed a correlation subanalysis investigating the amount of change in thoracic spine range of motion, CRP on the third postoperative day, and sex, because many previous studies have reported differing postural characteristics in men and women (34,35). The results showed that the range of thoracic spine motion decreased as CRP increased, especially in women. There were no differences in CRP levels between men and women on the third postoperative day, suggesting that women are more likely than men to experience changes in the same inflammation markers. It is possible that women were more susceptible to a reduction in mobility due to lower muscle strength and morphological differences associated with breast tissue in the chest area. However, there were methodological differences between the surgeries completed in men and women included in this study, including the method of fixation after sternotomy. Therefore, further research is needed in this area.

Strengths and limitations

The purpose of this study was to compare the range of motion of the spine before and after a median sternotomy and to analyze the factors that contribute to this range of motion. This is the first *in vivo* study to investigate the effects of a midline sternotomy and associated factors. Participants who experienced no effect on forward bending movements were included, and multiple adjustment variables were employed during multiple regression analysis and subanalysis. However, this study has several limitations. First, the study only included individuals with high baseline physical function. Due to the aging Japanese population, the number of patients with comorbidities and impaired physical function undergoing cardiac surgery is increasing. Individuals with poorer baseline function who were excluded due to their inability to stand or bend forward may have differing results. Second, participants had a wide range of indications for surgery, including surgeries with parasternal blood vessel manipulation; the impact that surgical indications have on outcomes need to be further investigated. Third, long-term changes were unknown as our study focused only on the perioperative period. The incised sternum fuses in approximately 3 months and the range of motion is then no longer limited; thus, the loss of range of motion may gradually improve. Fourth, the standard error of the measurement instrument used in this study, the Spinal Mouse, has been reported in a wide range from 1.0 to 5.5 in thoracic flexion (17,19). This suggests that the results of this study may be within the measurement error range and should be interpreted with caution.

Implications and actions needed

We believe that further research involving different measurement methods, increased sample sizes, and long-term follow-up is required. These studies will allow us to examine the significance of new rehabilitation interventions and perioperative management.

Conclusions

This study was conducted on patients who underwent cardiac surgery through a median sternotomy with the aim of analyzing pre- and postoperative changes in spinal range of motion and the factors contributing to these changes. Comparison of pre- and postoperative spinal range of motion showed a decrease in thoracic spine range of motion postoperatively. Perioperative factors involved in the reduced thoracic spine range of motion were examined, demonstrating a correlation with postoperative day 3 CRP measurements. The elevated CRP may be associated with a reduction in thoracic spine range of motion due to edema around the wound and thoracic area. However, the results of this study could also be due to standard errors of the equipment and further investigation and study is required.

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Footnote

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Data Sharing Statement: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1439/dss

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-1439/coif). A.I. reports Grant-in-Aid for Scientific Research (JSPS KAKENHI grant No. 19K19842). The other authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). This study was approved by the ethical committee of the International University of Health and Welfare (approval No. 17-Io-138) and informed consents were obtained from all individual participants.

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