

## Postoperative Change of Thoracic Kyphosis after Corrective Surgery for Adult Spinal Deformity

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### Abstract:

**Introduction:** Correction of lumbar lordosis is the primary goal of surgical treatment of adult spinal deformity. However, only limited research has evaluated the effects of this correction on the adaptive curvature of the thoracic spine. The purpose of this study is to evaluate the change in thoracic curvature after corrective surgery to restore lumbar lordosis in patients with adult spinal deformity.

**Methods:** We completed a retrospective analysis of the radiological data of 65 patients,  $\geq 50$  years old, who underwent corrective surgery of lumbar spine lordosis from any level below T8 to the ilium. Patients with insufficient correction, defined by a pelvic incidence minus lumbar lordosis angle (PI-LL)  $> 10^\circ$ , were excluded, with the data of 43 patients included in the analysis. The following radiological measures of spinal alignment were measured at three time points, preoperatively, on the first day of standing postoperatively and at 2 years post-surgery: sagittal vertical axis (SVA), lumbar lordosis (LL), thoracic kyphosis (TK), pelvic tilt (PT), and PI-LL.

**Results:** Postoperative change in TK was correlated to preoperative TK and age. The increase in TK was larger for patients  $< 75$  years of age, increasing from  $23.1^\circ$  to  $38.0^\circ$  after surgery and to  $46.7^\circ$  at 2-years postoperatively. In contrast, for patients  $> 75$  years, TK remained largely unchanged at  $37.8^\circ$  just after surgery but increased substantively to  $50.1^\circ$  at the 2-year follow-up. The postoperative change in TK immediately after surgery was determined using equation “predict change in TK =  $-0.21 \times \text{age} - 0.6 \times \text{preoperative TK} + 41.8$ ” by multiple regression analysis.

**Conclusions:** Reciprocal change in TK after lumbar spine correction is correlated to preoperative TK and age.

### Keywords:

adult spinal deformity, thoracic kyphosis, reciprocal change

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### Introduction

The impact of sagittal plane spinopelvic alignment, in addition to global spinal alignment parameters, on health-related quality of life has been well-described<sup>1-3)</sup>. Therefore, the usefulness of the T1 pelvis angle to quantify spinopelvic alignment has been evaluated<sup>4-6)</sup>.

Dubousset described the cone of economy concepts which indicate the energy cost of a poor sagittal alignment of the spine<sup>7)</sup>. Therefore, when spinal deformity with sagittal malalignment develops, multiple compensation mechanisms are observed, including reduction of the thoracic kyphosis (TK), retrolisthesis, hyperextension of adjacent segments, pelvic

retroversion, and knee flexion. A thorough understanding of compensatory mechanisms is necessary for the effective treatment of adult spinal deformity<sup>8)</sup>.

The goal of corrective surgery for the treatment of adult spinal deformity is to maintain or restore the sagittal alignment of the spine without compensations. Adequate lumbar lordosis is necessary to obtain *good* clinical results of spinal corrective fusion. Moreover, correction of the lumbar lordosis is the only parameter of spinal alignment that can be surgically modified. In fact, a number of formulas have been developed to predict the optimal correction in lumbar lordosis required to effectively restore spinopelvic alignment in the treatment of adult spinal deformity<sup>3,9,10)</sup>.

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**Table 1.** Demographic Data of Patients.

	PI-LL $\leq$ 10°	PI-LL $>$ 10°	P value
Number of patients	43 (66.1%)	22 (33.9%)	
Male:Female	5:38	2:20	0.75
Age	70.0 $\pm$ 7.4	71.7 $\pm$ 5.3	0.43

Previous studies have indicated that postoperative pelvic tilt can be predicted from the angle of incidence of the pelvis and the degree of lumbar lordosis<sup>9)</sup>. Due to the reciprocal relationship between the lumbar and thoracic segments of the spine, it has also been proposed that the alignment of the thoracic spine would be determined by the postoperative lumbar lordosis<sup>11)</sup>. However, the effects of correction of the lumbar lordosis on the alignment of the unfused segments of the thoracic spine have not been specifically evaluated. Therefore, the purpose of our retrospective study was to evaluate the change in TK after surgical restoration of optimal lumbar lordosis in patients treated for adult spinal deformity.

## Materials and Methods

### Patient sample

The study was approved by our institution's Clinical Ethics Committee. Our study group was formed of adult Japanese patients who underwent long corrective fusion surgery for the treatment of adult spinal deformity, between 2011 and 2014. Inclusion criteria for adult spinal deformity were patients with the presence of at least one of the following measures of spinal deformity: sagittal vertical axis (SVA) 5 cm or more, pelvic tilt (PT) 25° or greater, and TK (T5-12) 60° or greater. Our inclusion criteria were as follow: age  $\geq$  50 years, a minimum 2-year postoperative follow-up, the ilium as the lower instrumented vertebra, and upper instrumented vertebra (UIV) at T8 to T11, leaving sufficient unfused vertebrae for adaptive compensation of the thoracic spine. Decision-making for UIV was based on a thoracic curve. We preferred to stop at T6 or above as the UIV, if preoperative TK was more than 50°. Therefore, patients with preoperative TK  $>$  50° were excluded in this study. Based on each patient's characteristic, a posterior column osteotomy (PCO), pedicle subtraction osteotomy (PSO), or vertebral column resection (VCR) was selected as the corrective surgical technique. Sufficient correction of the lumbar lordosis was defined by a postoperative PI-LL  $\leq$  10°. Only the data of patients in whom a sufficient correction of the lumbar lordosis was achieved were included in the analysis. Patients who required revision surgery to change spinal alignment (rod exchange or fusion extension) within 2 years after the primary surgery were excluded in this study.

### Radiographic measurements

Radiographic evaluation was performed according to an

established positioning protocol for lateral, 36-inch, standing radiographs. The following five parameters of spinopelvic alignment were measured at three time points, preoperatively, immediately postoperatively (when standing was possible) and at a 2 year follow-up: SVA, lumbar lordosis (LL, L1-S1), TK, PT, and PI-LL.

### Patient outcomes

The Oswestry Disability Index (ODI) was used to evaluate patient outcomes before surgery and at the 2-year follow-up post-surgery.

### Data analysis

Correlation between each parameter of spinal alignment, as well as the correlation between measured parameters and age, was evaluated using Spearman's rank correlation coefficient. For identified significant correlations, between-group differences were evaluated using the Mann-Whitney U test. Analysis of variance followed by the Steel-Dwass test was used to detect differences of parameters among preoperative, postoperative, and 2 years after surgery. All statistical analyses were performed with EZR (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria).

## Result

### Relevant characteristics of the study group

Sixty-five patients met our inclusion criteria, with sufficient correction of the lumbar lordosis (postoperative PI-LL  $\leq$  10°) attained in 43 of these patients, who formed the study group: 5 male, 38 female, mean age of 70 years (Table 1). The diagnosis was degenerative kyphoscoliosis in 22 patients, degenerative kyphosis in 11, kyphosis with vertebral fracture in 7, iatrogenic flat back in 2, and adult idiopathic scoliosis in 1.

### Operative data

The following surgical techniques were used to correct the lumbar lordosis deformity: PCO in 29 patients, PSO in 10 patients, and VCR in 4 patients. All osteotomy was performed at the caudal from L2. The UIV was at the level of T8 in 3 patients, T9 in 15 patients, T10 in 23 patients, and T11 in 2 patients.

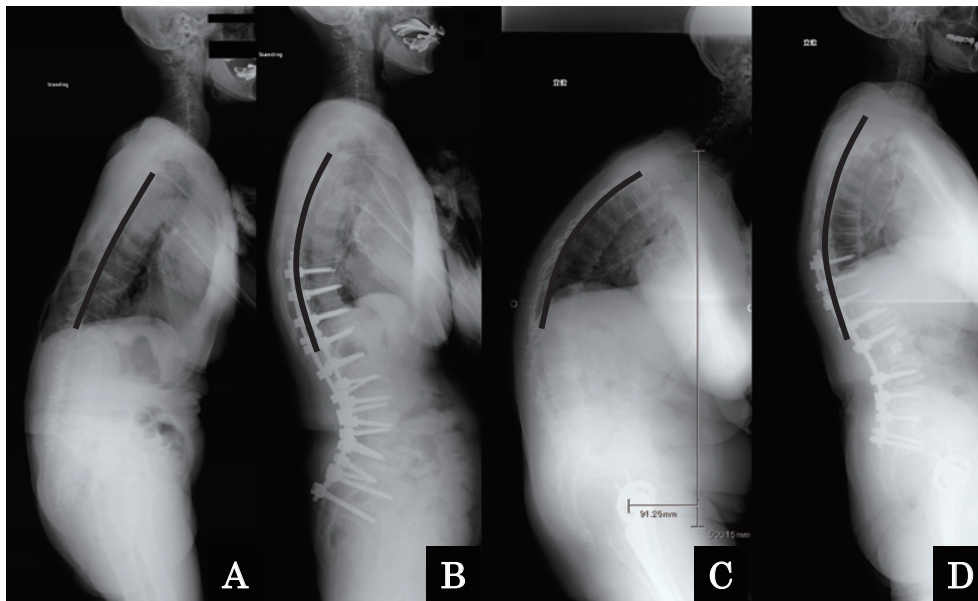
### Radiographic parameters of spinal alignment

Radiographic parameters of spinal alignment are summarized in Table 2. Overall, corrective surgery increased the LL from 13.0° to 48.5°, with a subsequent loss of about 5° over the 2-year follow-up after surgery. SVA improved significantly after surgery, from 103.4 mm (preoperatively) to 27.5 mm (immediately after surgery). However, SVA progressed to 45.9 mm over the 2-year follow-up period. Similarly, the anteversion in PT improved from 31.4° to 17.1°

**Table 2.** Radiographic Spinopelvic Parameters.

	preoperative	postoperative	2 years after surgery	P value (ANOVA)	P value (post hoc)
SVA (mm)	103.4±76.0	27.5±35.5	45.9±41.8	<0.001	<0.01 (a, b)
LL (°)	13.0±18.8	48.5±9.3	43.4±10.1	<0.001	<0.01 (a, b)
TK (°)	25.9±15.3	37.7±8.6	47.5±10.5	<0.001	<0.01 (a, b, c)
PT (°)	31.4±10.5	17.1±6.5	24.7±8.7	<0.001	<0.01 (a, b, c)
PI-LL (°)	33.9±22.2	0.28±8.2	8.7±12.9	<0.001	<0.01 (a, b)

Multiple comparison; a: preoperative vs. postoperative, b: preoperative vs. 2 years after surgery, c: postoperative vs. 2 years after surgery



**Figure 1.** (A) Radiograph showing the small preoperative TK of 19°, with the large postoperative increase in TK to 43° shown in (B). (C) Radiograph showing a large preoperative TK of 44°, with the small postoperative increase in TK to 43° shown in (D).

**Table 3.** Correlation Coefficient between Age and TK Parameters.

	Age	Pre TK	post TK	2-year TK	Change TK (pre→post)	Change TK (post→2-year)
Age		0.44**	0.14	0.43**	-0.47**	0.33*
pre TK	0.44		0.63**	0.60**	-0.83**	0.10
post TK	0.14	0.63**		0.47**	-0.09	-0.37*
2-yr TK	0.43	0.60**	0.47**		-0.44**	0.65**
Change TK (pre→post)	-0.47**	-0.83**	-0.09	-0.44**		-0.39*
Change TK (post→2-yr)	0.33*	0.10	-0.37*	0.65**	-0.39	

\* statistical significance at  $P < 0.05$   
 \*\* statistical significance at  $P < 0.01$

with surgery and subsequently increased to 24.7° of retroversion at the 2-year follow-up. With regards to the thoracic spine specifically, TK increased from 25.9° to 37.7° immediately after surgery, further increasing to 47.5° at the 2-year follow-up.

**Correlation between postoperative change in thoracic kyphosis, other spinal alignment parameters, and age**

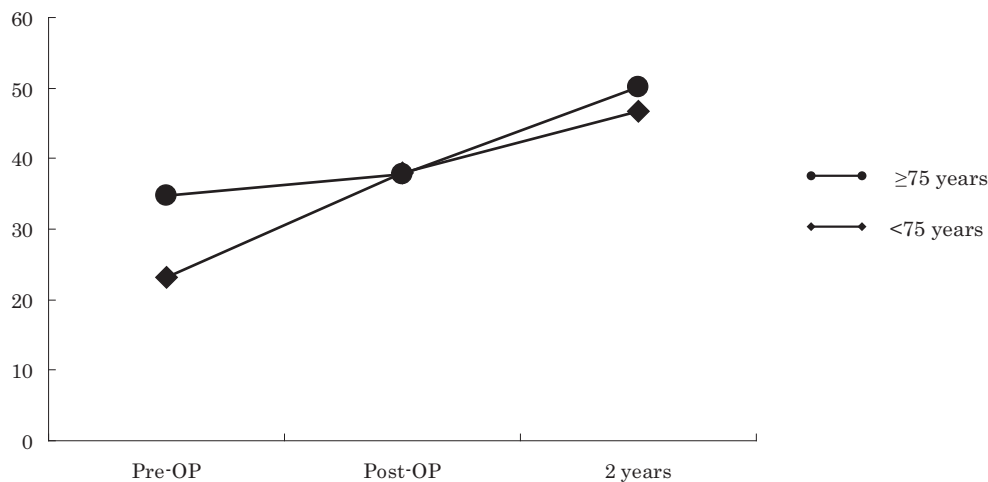
The postoperative change in TK was negatively correlated

to the preoperative measure of TK ( $r = -0.83, p < 0.001$ ). Therefore, the change in TK immediately after surgery was small if the preoperative TK angle was large and, alternatively, the change was large if the preoperative TK angle was small (Fig. 1). The postoperative change in TK had no significant correlation with the change in LL, or with any other radiographic parameter of spinal alignment.

Moreover, TK and change in TK correlated with patient's age (Table 3). The postoperative change in TK immediately

**Table 4.** Radiographic Parameters (<75 Years Vs. ≥75 Years).

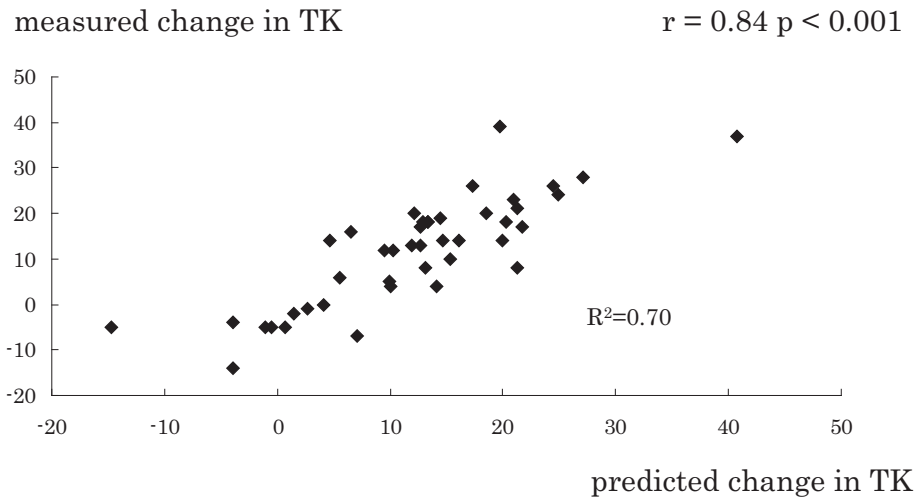
	preoperative			postoperative			2 years after surgery		
	<75 years	≥75 years	P value	<75 years	≥75 years	P value	<75 years	≥75 years	P value
SVA (mm)	102.7±77.8	106.2±71.6	0.50	22.2±34.6	42.1±34.2	0.05	43.3±39.2	52.8±47.1	0.52
LL (°)	12.7±19.9	15.5±16.9	0.65	48.7±9.3	48.3±9.5	0.98	43.0±11.3	41.5±12.6	0.58
TK (°)	23.1±14.3	34.8±16.5	0.04	38.0±8.4	37.8±9.4	0.79	46.7±11.3	50.1±8.0	0.57
PT (°)	30.2±8.6	34.2±13.9	0.37	16.8±6.3	16.8±7.8	0.79	24.2±7.8	25.3±10.7	0.98
PI-LL (°)	34.3±22.6	33.1±21.8	0.81	-0.2±8.6	0.7±7.7	0.83	8.7±12.4	8.7±15.6	0.88



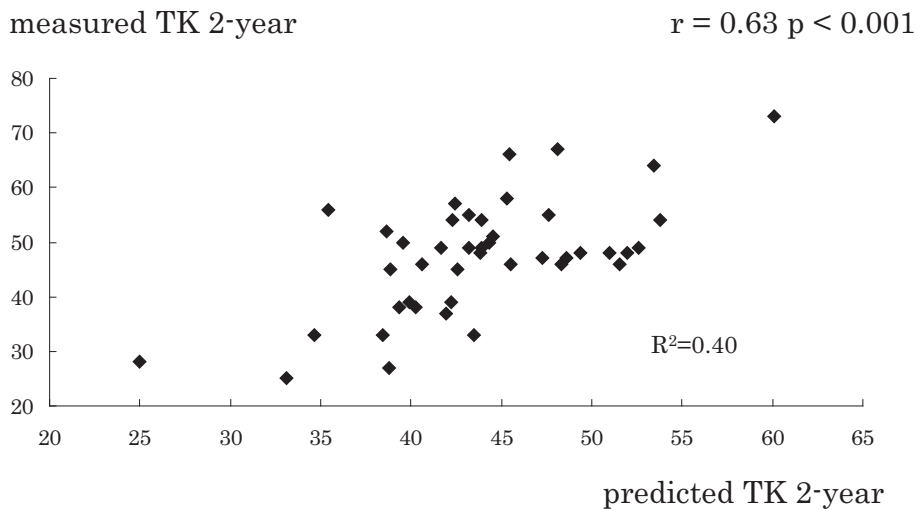
**Figure 2.** The change in TK from preoperatively to the 2-year follow-up is shown for patients ≥75 years old (●) and <75 years old (◆). The preoperative TK was small in patients <75 years of age (23.1°), increasing significantly postoperatively (38.0°), with a slight progression at 2-years postoperatively (46.7°). For patients ≥75 years old, preoperative TK was comparatively larger at 34.8°, with a modest increase postoperatively (37.8°) and a substantive increase at 2 years (50.1°). In the <75-year-old group, TK increased by 23.6° from the preoperative period to 2-years after surgery; it increased by 63.1% (14.9°) from the preoperative period to immediately after surgery and by 36.9% (8.7°) from immediately after surgery to 2-years after surgery. In the ≥75-year-old group, TK increased by 15.3° from the preoperative period to 2-years after surgery; it increased by 19.6% (3.0°) from the preoperative period to immediately after surgery and 80.4% by (12.3°) from immediately after surgery to 2-years after surgery.

after surgery was negatively correlated to age ( $rs = -0.47$ ,  $p = 0.001$ ), with a positive correlation for the change in TK at the 2-year follow-up ( $rs = 0.33$ ,  $p = 0.03$ ). It is important to note that age was also significantly correlated to preoperative TK ( $rs = 0.44$ ,  $p = 0.002$ ) and to the magnitude of change in TK at the 2-year follow-up ( $rs = 0.42$ ,  $p = 0.004$ ). Therefore, older patients would be expected to have larger TK values preoperatively, a smaller change in TK immediately after surgery, and a large change at the 2-year follow-up. To evaluate the age-related effects, patients were divided into two groups (<75 years of age and ≥75 years: Table 4) and between-group differences in TK were evaluated at the three time points of measurement (Fig. 2). Thirty patients were assigned to <75 years old group, and 13 patients were assigned to ≥75 years old group. Preoperatively, TK was relative smaller (23.1°) in patients <75 years old than in patient ≥75 years old (34.8°). Immediately post-surgery, the TK increased to 38.0° in patients <75 years old, with a fur-

ther increase to 46.7° at the 2-year follow-up. In contrast, for patients ≥75 years old, TK increased modestly to 37.8° immediately after surgery, with a substantial increase to 50.1° at the 2-year follow-up. The change in TK immediately after surgery in patients <75 years old was significantly larger than patients ≥75 years old ( $p = 0.01$ ). The change in TK from immediately after surgery to 2-years after surgery and from preoperative to 2-years after surgery was not significantly different between the two groups ( $p = 0.57$ ,  $p = 0.06$ ). In the <75-year-old group, TK increased by 23.6° from the preoperative period to 2-years after surgery; it increased by 63.1% (14.9°) from the preoperative period to immediately after surgery and by 36.9% (8.7°) from immediately after surgery to 2-years after surgery. In the ≥75-year-old group, TK increased by 15.3° from the preoperative period to 2-years after surgery; it increased by 19.6% (3.0°) from the preoperative period to immediately after surgery and 80.4% by (12.3°) from immediately after surgery to 2-



**Figure 3.** The scatter plots predicted change in TK after surgery (predicted change in TK) and measured change in TK after surgery (measured change in TK).



**Figure 4.** The scatter plots predicted TK at 2 year follow-up (predicted TK 2 year) and measured TK at 2-year follow-up (measured TK 2 year).

years after surgery.

**Predicted reciprocal change of thoracic kyphosis and post-operative kyphosis**

The postoperative change in TK immediately after surgery had correlated with age and preoperative TK. Thus, the postoperative change was determined as a function of age and preoperative TK using multiple regression analysis. The postoperative change in TK immediately after surgery was determined using equation “predict change in TK =  $-0.21 \times \text{age} - 0.6 \times \text{preoperative TK} + 41.8$ .” The postoperative change in TK value calculated using this equation was strongly correlated with the postoperative change in TK value measured on radiographs ( $R^2 = 0.70$ ) (Fig. 3).

TK at the 2-year follow-up was also determined as a function of age and preoperative TK using multiple regression analysis. TK at the 2-year follow-up was assessed using equation “TK (2 years) =  $0.28 \times \text{age} + 0.35 \times \text{preoperative TK}$

+ 18.7.” TK at 2-year follow-up value calculated using this equation was moderately correlated with TK at 2-year follow-up value measured on radiographs ( $R^2 = 0.40$ ) (Fig. 4).

**Clinical outcomes**

The average of ODI scores decreased from 47.9 to 29.8 at the 2-year follow-up, with a lower ODI score being indicative of a better clinical outcome. There was no correlation between TK or the postoperative change in TK and the ODI score.

**Discussion**

Lumbar degenerative kyphosis, first described by Takemitsu et al., is the primary cause of sagittal plane imbalance and loss of alignment of the spine<sup>12</sup>. The sagittal imbalance at the lumbar spine can be compensated at various levels,

including the cervical spine, thoracic spine, pelvis, and lower limbs<sup>13-15</sup>). Among these possible compensatory strategies, pelvic retroversion and reduction of the TK provide the primary compensation. It has been suggested that, due to the reciprocal nature between the alignment of the lumbar and thoracic segments of the spine, correction of the lumbar lordosis would lead to improvement in TK<sup>11</sup>). However, specific postoperative evaluation of TK is difficult as the alignment of the thoracic spine will be influenced by correction in lumbar spine alignment and compensatory mechanisms for sagittal imbalance, which can extend from the lower limbs to the cervical spine. To our knowledge, our study is the first to provide a specific evaluation of the change in TK in patients with adult spinal deformity who underwent sufficient lumbar corrective surgery ( $PI-LL \leq 10^\circ$ ), excluding the contribution of additional compensatory postures.

An important finding of our study was the significant correlation between the extent of postoperative change in TK and preoperative TK measurement and age. Based on these findings, the postoperative change in TK might be influenced by the preoperative compensation ability at thoracic level. We also identified a progressive increase in TK of about  $10^\circ$  from immediate postoperative alignment to through to the 2-year follow-up. Moreover, the increase in TK after corrective LL surgery was associated with an increase in SVA through to the 2-year follow-up. Clinically, therefore, TK and SVA can be expected to increase over time after corrective surgery, even if optimal correction of the lumbar spine lordosis was achieved immediately after surgery. As the change in ODI score at the 2-year follow-up, from preoperative baseline, was within previously reported minimum detectable difference limit for a meaningful improvement in clinical outcomes after adult spinal deformity surgery<sup>16</sup>), we considered that the increase in TK and SVA over the 2-year follow-up was clinically acceptable.

Proximal junctional failure which requires revision surgery for proximal junctional kyphosis is one of the important complications in adult spinal deformity surgery. Because all of the cases which required revision surgery to change spinal alignment were excluded, proximal junctional failure cases were not able to investigate in this study. Although the knowledge of reciprocal change in TK might be predicted proximal junctional failure, more study about reciprocal change in TK had needed.

With regards to our identified correlation between age and postoperative change in TK, the relatively small TK in patients <75 years of age may be indicative of the capacity for compensation for a loss of sagittal alignment at the lumbar spine. Conversely, the larger preoperative TK in patients  $\geq 75$  years old is likely to be indicative of a decrease in compensatory capacity for loss of sagittal spine alignment. This progressive loss of compensatory capacity in older individuals could explain the substantial increase in TK over the 2-year follow-up period after corrective surgery. Further research is needed to fully characterize the compensatory capacity of the thoracic spine over a wide range of ages, and to identify

possible age cutoffs that might lead to large increases in TK after corrective lumbar surgery. Moreover, the effects of insufficient lumbar lordosis on age-related changes in the compensatory capacity would also need to be clarified.

In this study, the postoperative change in TK immediately after surgery was determined using equation “predict change in TK =  $-0.21 \times \text{age} - 0.6 \times \text{preoperative TK} + 41.8$ .” This prediction accuracy was high. Thus, postoperative reciprocal change in TK immediately after surgery is able to predict from patient’s age and preoperative TK value. The prediction of the TK at 2-year follow-up was lower than change in TK immediately after surgery. Thoracic curve might be affected by various factors for 2 years even if the patient had sufficient lumbar lordosis.

Several limitations of this study should be acknowledged. There were no dates about flexibility of thoracic spine before surgery. Although assessment of flexibility is important for prediction of reciprocal change of thoracic curve, evaluation method of flexibility at thoracic spine has not been established. Moreover, lower thoracic was included as segmental fusion area, thereby it might not indicate true reciprocal change.

## Conclusion

The reciprocal change in TK after corrective surgery was correlated to the preoperative TK and age. The postoperative change in TK immediately after surgery was determined using equation “predict change in TK =  $-0.21 \times \text{age} - 0.6 \times \text{preoperative TK} + 41.8$ ”. The change in TK immediately after surgery in patients <75 years old was significantly larger than patients  $\geq 75$  years old.

**Conflicts of Interest:** Daisuke Togawa and Shin Oe belong to donated fund laboratory called Division of Geriatric Musculoskeletal Health.

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**Author Contributions:** Tatsuya Yasuda wrote and prepared the manuscript, and all of the authors participated in the study design. All authors have read, reviewed, and approved the article.

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