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Does Adult Spinal Deformity Affect Cardiac Function? A Prospective Perioperative Study

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Study Design. Prospective comparative study.

Objective. The objective of this study was to investigate perioperative cardiac function using echocardiography in patients undergoing surgery for the adult spinal deformity (ASD).

Summary of Background Data. Corrective surgery for ASD has increased, especially in older persons. However, perioperative complication rates remain high in ASD surgery, including cardiopulmonary complications.

Materials and Methods. This study included patients with ASD who underwent surgery between May 2016 and April 2018. A cardiologist performed all echocardiography imaging preoperatively and 2 weeks postoperatively. Left ventricular contractility was measured using left ventricular ejection fraction (LVEF), and right ventricular contractility was measured using tricuspid annular plane systolic excursion (TAPSE) and tricuspid annular peak systolic velocity (S′). Spinopelvic radiographic parameters, the apices of thoracic kyphosis and lumbar lordosis, and the inflection point where the vertebral curvature changes from kyphosis to lordosis were also measured. Differences between preoperative and postoperative measurements for continuous variables were analyzed using a paired Student *t* test. Differences in continuous and categorical variables between two independent groups were analyzed using an unpaired Student *t* test and Fisher exact test, respectively. Multivariate logistic regression analyses were performed to detect influential factors.

Results. Sixty-one patients were included [12 males and 49 females; average age, 64.0 (22–84) yr]. LVEF, TAPSE, and S′, respectively changed from 64.4%, 24.9 mm, and 14.3 cm/s to 65.4%, 25 mm, and 15 cm/s postoperatively with no significance. However, in LVEF < 59.3% (average−1 SD), TAPSE < 17 mm, and S′ < 11.8 cm/s cases, respectively, these increased significantly from 55.7%, 17.9 mm, and 10.5 cm/s to 60.9%, 21.4 mm, and 14.2 cm/s postoperatively ($P=0.036$, 0.029, and 0.022, respectively). The LVEF < 59.3% group showed a significantly lower inflection point level (1.5 *vs.* 2.9) preoperatively ($P=0.007$). The S′ < 11.8 cm/s group showed significantly larger thoracic kyphosis (28.3° *vs.* 19.4°) preoperatively ($P=0.013$).

Conclusions. Perioperative cardiac function did not deteriorate after surgery in patients with ASD. In those with lower cardiac function preoperatively, there were significant improvements noted postoperatively. The preoperative inflection point level was significantly lower in the lower LVEF group. Preoperative thoracic kyphosis was significantly larger in the lower tricuspid annular peak systolic velocity group.

Key words: adult spinal deformity, cardiac function, prospective study, kyphosis, echocardiography, corrective fusion surgery, sagittal radiographic parameter, left ventricular ejection fraction, tricuspid annular plane systolic excursion, annular peak systolic velocity

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Corrective fusion surgery for the adult spinal deformity (ASD) has increased in recent decades, especially among older persons. Rapid population aging in developed countries might accelerate the incidence of ASD patients.[1] The prevalence rate of ASD has been estimated to be as high as 68% among older persons.[2] With the increase in the incidence of ASD, remarkable progress has been made in diagnostics and therapeutic approaches,[3–6] including surgical techniques.[7–9]

Moreover, the importance of health-related quality of life evaluation has become more apparent,[10–14] and there are reports that postoperative health-related quality of life improved more following ASD surgery than that of non-surgical cases.[15,16] However, perioperative complication rates in ASD surgery are still high (13.7%–26.8%), including cardiopulmonary events.[1,17–20] Pulmonary function has been assessed in patients with adolescent idiopathic scoliosis (AIS).[21–24] Pulmonary function improvement was observed 2 years after posterior fusion surgery in a prospective study of patients with AIS.[22] However, there are relatively few reports on pulmonary function in patients with ASD.[25–27] Bumpass *et al*[25] reported pulmonary function improvement after posterior vertebral column resection in patients with ASD.

Furthermore, there are few reports on cardiac function, even in patients with AIS.[28–30] There are no reports about cardiac function in ASD cases. Lorente *et al*[31] evaluated cardiorespiratory function in patients undergoing surgery for AIS in instances of Lenke type 1A, measuring heart rate and blood pressure at maximal exercise. Lin *et al*[32] also investigated cardiorespiratory function using exercise testing in patients with congenital scoliosis. However, these are not direct evaluations of cardiac function as seen in echocardiographic evaluations.

Spinal deformity–induced cardiac dysfunction has been reported in patients with congenital scoliosis.[33] Cardiac function assessment is also clinically important in patients with ASD. Therefore, this study aimed to investigate acute phase perioperative cardiac function using echocardiographic evaluation in patients undergoing corrective surgery for ASD.

MATERIALS AND METHODS

The study protocol was approved by the Institutional Review Board of Hamamatsu University School of Medicine, Shizuoka, Japan (15-273). Any experimental investigation with human participants reported in this manuscript was performed with informed consent. This prospective study included 67 patients [13 males and 54 females; average age, 64.0 (22–84) yr] with ASD who underwent corrective fusion surgery from May 2016 to April 2018. ASD was defined as the presence of at least one of the following: spinal curvature of $\geq$20° in the coronal plane, C7–sagittal vertical axis (SVA) $\geq$50 mm, pelvic tilt (PT) $\geq$25°, and/or thoracic kyphosis (TK) $\geq$60°.

Measured Parameters

Echocardiography and whole spine standing radiography were performed at the first visit and 2 weeks postoperatively. All echocardiography imaging tests were performed by a cardiologist certified by the Japanese Society of Cardiology in our hospital. Left ventricular ejection fraction (LVEF) was used as the measure of left ventricular contractility. Tricuspid annular plane systolic excursion (TAPSE) and tricuspid annular peak systolic velocity (S') by pulsed tissue Doppler imaging were used as measures of right ventricular contractility. The coronal curve types T (thoracic only), L (thoracolumbar/lumbar only), D (double curve), and N (no major coronal deformity) were evaluated according to Schwab's classification.[3] The measured parameters in the whole spine standing radiographs were as follows: C7–SVA, TK, thoracolumbar kyphosis (TLK: Cobb angle between T10 superior endplate and L2 inferior endplate), lumbar lordosis (LL: Cobb angle between L1 and S1 superior endplate), L4–S: Cobb angle between L4 and S1 superior endplate, pelvic incidence (PI), sacral slope, and PT (Figures 1 and 2). Furthermore, geometrical radiologic parameters were measured as follows: thoracic apex (TA), TA–SVA, inflection point, inflection point–SVA, lumbar apex (LA), and LA–SVA as previously described (Figure 3).[34] The apices of LL and TK were determined as the most horizontal vertebral body. When the inclination of the two vertebral bodies was comparable, it was determined as the intervertebral space between vertebrae. The inflection point was defined as a vertebra or disk where the sagittal curvature of the spine changes from kyphosis to lordosis. At the inflection point, the thoracic and lumbar curves are tangent to a perpendicular

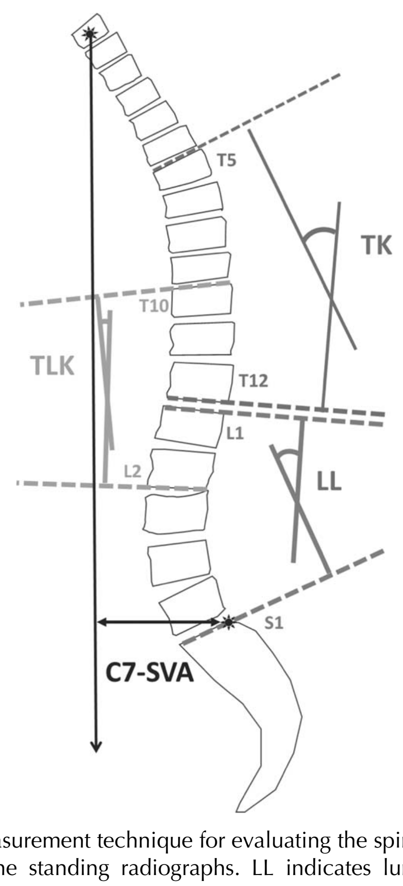

Figure 1. Measurement technique for evaluating the spinal parameters in whole spine standing radiographs. LL indicates lumbar lordosis; SVA, sagittal vertical axis; TK, thoracic kyphosis; TLK, thoracolumbar kyphosis.

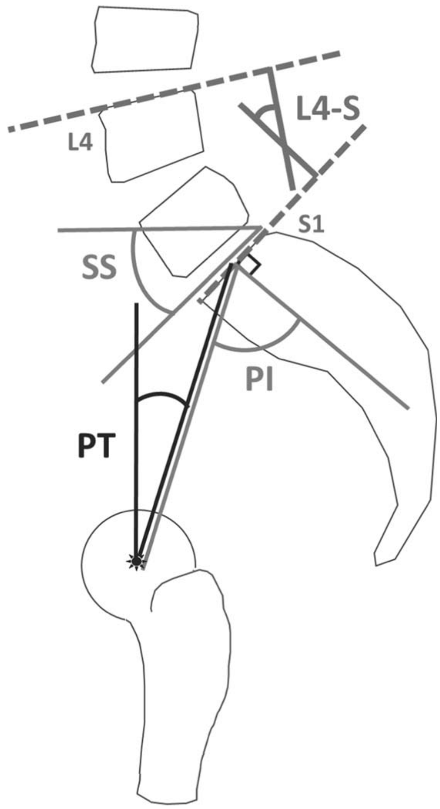

Figure 2. Measurement technique for evaluating the spinopelvic parameters in whole spine standing radiographs. PI indicates pelvic incidence; PT, pelvic tilt; SS, sacral slope.

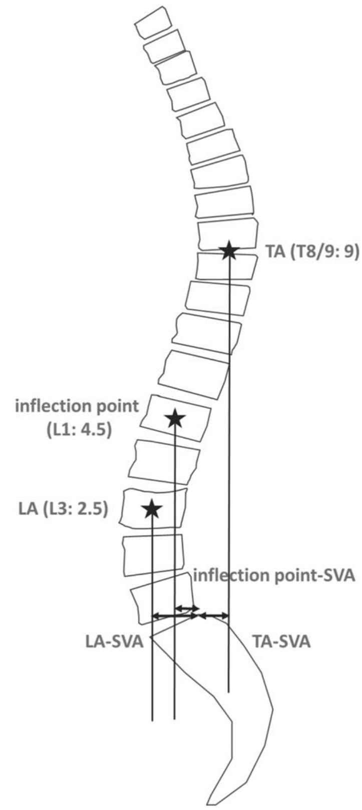

Figure 3. Measurement technique for evaluating the apices and inflection point. The positions of apices were determined using the spinal level. The distances between the plumb line of apices and the posterolateral corner of the S1 upper endplate were measured. LA indicates lumbar apex; SVA, sagittal vertical axis; TA, thoracic apex.

line to the inferior end of kyphosis and the superior end of lordosis. The levels of the apexes and inflection points were defined using the following rules: L5/S1 disk = 0, L5 vertebral body = 0.5, L4/L5 intervertebral disk = 1.0, and L4 vertebral body = 1.5…C7 = 17.5. Respiratory function was evaluated using vital capacity (VC), %VC, and percent forced expiratory volume in 1 second.

Data and Statistical Analysis

LVEF was set as the primary outcome. The sample size calculation was conducted using G-power software. Based on an a priori power analysis, a total sample size of 54 was required to have 95% power to detect a statistically significant difference between two dependent means, assuming an α value of 0.05, when using a two-tailed t test.[35]

All data were analyzed using IBM SPSS Statistics for Windows, version 23.0 (IBM Corp., Armonk, NY). Demographic variables were analyzed using descriptive statistics. Differences between preoperative and postoperative measurements for continuous variables were analyzed using a paired Student t test. Differences in continuous and categorical variables between two independent groups were analyzed using an unpaired Student t test and Fisher exact test, respectively. Multivariate logistic regression analyses were performed to detect influential factors. Statistical significance was set at a P-value <0.05.

RESULTS

Among the 67 patients, six were excluded: consent for participating in the study could not be obtained preoperatively (n = 2), severe aortic valve stenosis in the preoperative echocardiographic evaluation (n = 1), and postoperative echocardiography not performed due to the absence of the cardiologist (n = 2). Finally, 61 patients were included: 12 males and 49 females [average age, 64.0 (22–84) yr]. The average fusion area was 10.0 segments, and 51 patients were fused to the ilium using iliac screws. The types of ASD were as follows: 35 kyphoscoliosis, eight idiopathic scoliosis, seven kyphosis, six iatrogenic kyphosis, three neuromuscular kyphoscoliosis, one spinal caries, and one posttraumatic kyphosis. Coronal curve types were as follows: 3 (4.9%) type T, 36 (59%) type L, 21 (34.4%) type D, and 1 (1.6%) type N. Types L and D, including thoracolumbar curve, were dominant. TA was 4.9 (around L1/L2 level), inflection point 2.7 (around L3 level), LA 0.9 (around L4/L5 level) (Table 1). The average LVEF, TAPSE, and S', respectively changed from 64.4%, 180 mm, and 16.7 cm/s preoperatively to 65.4%, 176 mm, and 15 cm/s postoperatively; however, the differences were not significant (P = 0.126, 0.437, and 0.503). Average radiographic parameters improved significantly postoperatively: C7–SVA, from 100.7 to 43.7 mm; TK, 20.2° to 31.7°; PT, 33.8° to 20.2°; and PI–LL, 38.9° to 10° (all P < 0.001). Postoperative whole spine

TABLE 1. Demographic and Perioperative Data

	N = 61
Age (yr)	64.0 ± 14.3
Sex	
Male	12 (19.7)
Female	49 (80.3)
Height (cm)	152.2 ± 9.9
Weight (kg)	54.3 ± 11.4
BMI (kg/m^2)	23.4 ± 4.0
LVEF (%)	64.4 ± 5.1
TAPSE (mm)	24.9 ± 4.9
S′(cm/s)	14.3 ± 2.5
Coronal curve types	
T	3 (4.9)
L	36 (59.0)
D	21 (34.4)
N	1 (1.6)
Cobb angle (°)	34.4 ± 21.0
C7–SVA (mm)	99.4 ± 76.4
TK (°)	20.5 ± 17.3
TLK (°)	20.0 ± 20.5
LL (°)	12.7 ± 20.9
L4–S (°)	23.1 ± 16.2
PI (°)	51.5 ± 9.8
SS (°)	17.2 ± 11.4
PT (°)	34.1 ± 11.0
PI–LL (°)	38.8 ± 21.2
TA	4.9 ± 3.1
TA–SVA (mm)	−9.0 ± 34.1
Inflection point	2.7 ± 1.5
Inflection point–SVA (mm)	6.9 ± 21.2
LA	0.9 ± 1.1
LA–SVA (mm)	22.2 ± 10.1
VC (mL)	2781 ± 893
%VC (%)	102.5 ± 19.9
FEV1.0% (%)	78.0 ± 7.1

Continuous data are presented as mean ± SD of median. Categorical data are presented as n (%).

BMI indicates body mass index; FEV1.0%, percent forced expiratory volume in 1 second; LA, lumbar apex; LL, lumbar lordosis; LVEF, left ventricular ejection fraction; PI, pelvic incidence; PT, pelvic tilt; S′, tricuspid annular peak systolic velocity; SS, sacral slope; SVA, sagittal vertical axis; TA, thoracic apex; TAPSE, tricuspid annular plane systolic excursion; TK, thoracic kyphosis; TLK, thoracic lumbar kyphosis; VC, vital capacity.

TABLE 2. Comparisons Between Pre- and Postoperative Parameters

	Preoperative	Postoperative	*P*
N = 61			
LVEF (%)	64.4 ± 5.1	65.4 ± 4.7	0.126
TAPSE (mm)	24.9 ± 4.9	25.0 ± 5.0	0.856
S′ (cm/s)	14.3 ± 2.5	15.0 ± 2.8	0.074
Inflection point	2.7 ± 1.5	4.3 ± 0.9	< 0.001*
N = 60			
Cobb angle (°)	34.9 ± 20.9	12.3 ± 8.8	< 0.001*
C7–SVA (mm)	100.7 ± 76.4	43.7 ± 54.6	< 0.001*
TK (°)	20.2 ± 17.3	31.7 ± 13.1	< 0.001*
TLK (°)	19.7 ± 20.5	10.8 ± 11.0	< 0.001*
LL (°)	12.5 ± 21.1	41.9 ± 11.9	< 0.001*
L4–S (°)	23.2 ± 16.3	28.2 ± 11.0	0.004*
PI (°)	51.4 ± 9.8	51.7 ± 9.9	0.442
SS (°)	17.2 ± 11.4	31.6 ± 8.9	< 0.001*
PT (°)	33.8 ± 10.8	20.2 ± 10.3	< 0.001*
PI–LL (°)	38.9 ± 21.4	10.0 ± 12.9	< 0.001*
TA	4.9 ± 3.1	9.2 ± 1.8	< 0.001*
TA–SVA (mm)	-9.0 ± 34.1	-23.7 ± 29.2	< 0.001*
Inflection point–SVA (mm)	7.1 ± 21.3	3.7 ± 19.1	0.146
LA	0.9 ± 1.1	1.7 ± 0.8	< 0.001*
LA–SVA (mm)	22.2 ± 10.1	27.7 ± 9.7	< 0.001*
N = 56			
VC (mL)	2763 ± 916	2331 ± 788	< 0.001*
%VC (%)	102.9 ± 20.3	84.9 ± 20.9	< 0.001*
FEV1.0% (%)	77.9 ± 7.3	79.2 ± 8.0	0.166

Continuous data are presented as mean ± SD of median.

FEV1.0% indicates percent forced expiratory volume in 1 second; LA, lumbar apex; LL, lumbar lordosis; LVEF, left ventricular ejection fraction; PI, pelvic incidence; PT, pelvic tilt; S′, tricuspid annular peak systolic velocity; SS, sacral slope; SVA, sagittal vertical axis; TA, thoracic apex; TAPSE, tricuspid annular plane systolic excursion; TK, thoracic kyphosis; TLK, thoracic lumbar kyphosis; VC, vital capacity.

**Statistically significant.*

standing radiographs could not be taken in one case (Figure 4), and we evaluated postoperative radiographic parameters in the other cases. Only the postoperative inflection point was measured as a reference in that one case. The average %VC decreased significantly from 102.9% to 84.9% postoperatively. Five patients did not undergo postoperative pulmonary function tests, which were evaluated in the other 56 patients (Table 2).

The patients were divided into two groups based on preoperative LVEF: <59.3% (average–1 SD) and ≥ 59.3%. In the LVEF <59.3% group, the average LVEF significantly increased from 55.7% to 60.9% postoperatively ($P = 0.036$). Moreover, in patients with an LVEF <55% (considered an abnormal value according to guideline[36]), the average LVEF also significantly increased from 51.1% to 63.4% postoperatively ($P = 0.038$). LVEF increased postoperatively in all three cases of LVEF <55% (Table 3 and Figures 4 and 5). In contrast, no significant LVEF change was observed postoperatively in the LVEF ≥ 59.3% group (from 66.1 ± 3.2% to 66.3 ± 4.1%;

TABLE 3. Changes in LVEF, TAPSE and S′ Before and After Surgery

	Preoperative	Postoperative	*P*
LVEF (%)			
All cases (n = 61)	64.4 ± 5.1	65.4 ± 4.7	0.126
LVEF < 59.3% (n = 10)	55.7 ± 3.6	60.9 ± 4.9	0.036*
LVEF < 55% (n = 3)	51.1 ± 3.4	63.4 ± 5.1	0.038*
Case 1	47.3	58.9	
Case 2	52.0	68.9	
Case 3	54.1	62.5	
TAPSE (mm)			
All cases (n = 61)	24.9 ± 4.9	2.5 ± 0.5	0.856
TAPSE < 20 mm (n = 11)	17.9 ± 2.1	21.4 ± 3.9	0.029*
TAPSE < 16 mm (n = 3)	14.7 ± 0.7	21.5 ± 5.3	0.184
Case 1	14.1	23.8	
Case 2	14.7	25.3	
Case 3	15.4	15.4	
S′ (cm/s)			
All cases (n = 61)	14.3 ± 2.5	15.0 ± 2.8	0.074
S′ < 11.8 cm/s (n = 8)	10.5 ± 1.0	14.2 ± 3.7	0.022*
S′ < 10 cm/s (n = 3)	9.5 ± 0.5	13.1 ± 3.2	0.176
Case 1	8.8	10.2	
Case 2	9.4	16.5	
Case 3	9.9	12.5	

Continuous data are presented as mean ± SD of median.
LVEF indicates left ventricular ejection fraction; S′, tricuspid annular peak systolic velocity; TAPSE, tricuspid annular plane systolic excursion.
**Statistically significant*

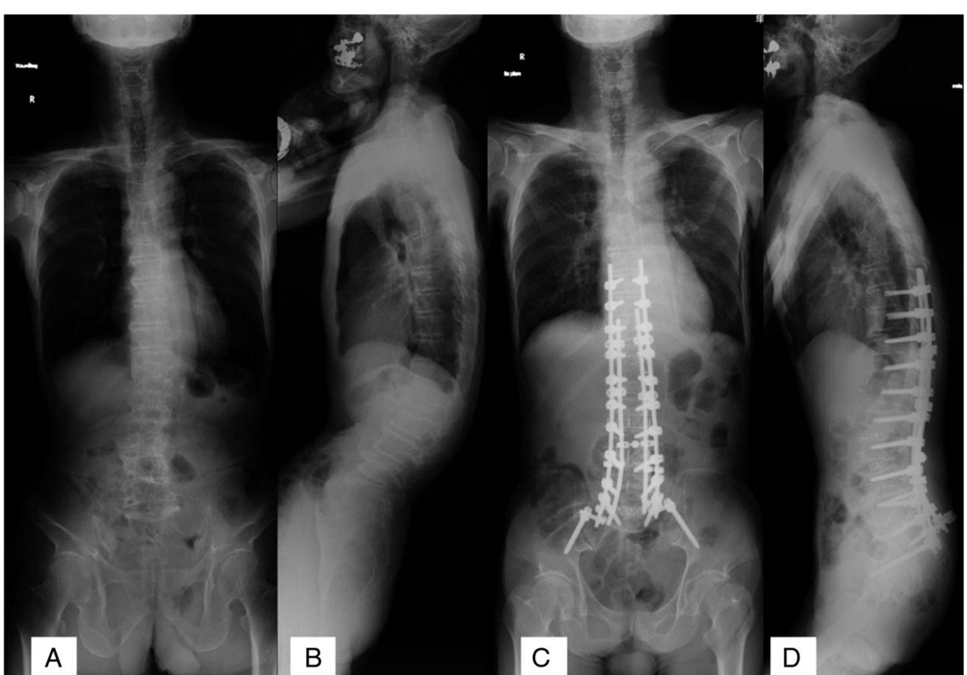

Figure 4. A 71-year-old male patient with spinal kyphosis. Left ventricular ejection fraction changed from 52% to 69%, and inflection point level changed from L4 to L1 postoperatively. Whole spine radiographs were performed in the standing position (A, B) preoperatively and in the supine position (C, D) postoperatively.

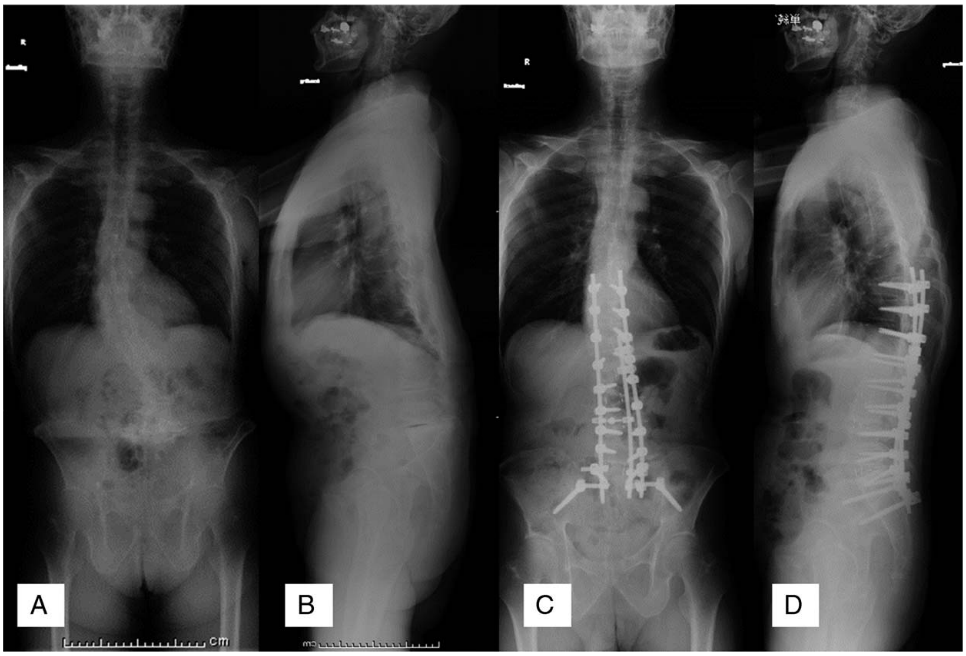

Figure 5. A 59-year-old male patient with spinal kyphoscoliosis. Left ventricular ejection fraction changed from 47% to 59%, and inflection point level changed from L3 to T12 postoperatively. Whole spine radiographs were performed in the standing position (A, B) preoperatively and (C, D) postoperatively.

$P=0.745$). The patients were also divided into two groups based on preoperative TAPSE: <20 mm (average–1 SD) and ≥ 20 mm. In the TAPSE < 20 mm group, the average TAPSE significantly increased from 17.9 to 21.4 mm postoperatively ($P=0.029$). In patients with a TAPSE <16 mm (considered an abnormal value according to guidelines[37]), TAPSE did not decrease postoperatively in all three cases (Table 3). In contrast, no significant change in TAPSE was observed postoperatively in the TAPSE ≥ 20 mm group (from 26.4 ± 3.9 to 25.8 ± 4.9 mm; $P=0.393$). Furthermore, patients were divided into two groups based on preoperative S': <11.8 cm/s (average –1 SD) and ≥ 11.8 cm/s. In the S' <11.8 cm/s group, the average S' significantly increased from 10.5 to 14.2 cm/s postoperatively ($P=0.022$). In patients with an S' <10 cm/s (considered an abnormal value according to guidelines[37]), S' increased postoperatively in all three cases (Table 3). In contrast, no significant change in S' was observed postoperatively in the S' ≥ 11.8 cm/s group (from 14.9 ± 2.2 to 15.1 ± 2.7 cm/s; $P=0.452$).

There were 10 patients (three males and seven females; average age, 58.8 yr) in the LVEF <59.3% group and 51 patients (9 males and 42 females; average age, 65.1 yr) in the LVEF $\geq 59.3\%$ group. There were no significant differences in sex ($P=0.368$) and age ($P=0.211$) between the two groups. The LVEF < 59.3% group showed a significantly higher height (159.8 *vs.* 150.7 cm; $P=0.007$) and a lower inflection point level (1.5 *vs.* 2.9; $P=0.007$) preoperatively. However, there were no significant differences in other parameters between the LVEF <59.3% and $\geq 59.3\%$ groups (Table 4). There were no significant differences in all parameters postoperatively (Table 5).

There were 11 patients (two males and nine females; average age, 63.6 yr) in the TAPSE <20 mm group and 50 patients (10 males and 40 females; average age, of 64.1 yr) in the TAPSE ≥ 20 mm group. There were no significant differences in sex ($P=0.921$) and age (1.000) between the two groups. There were no significant differences in all parameters preoperatively (Table 4). The TAPSE <20 mm group showed a significantly lower TA (8.1 *vs.* 9.5) postoperatively ($P=0.024$). Other parameters showed no significant differences between the TAPSE <20 and ≥ 20 mm groups postoperatively (Table 5).

There were eight patients (one male and seven females; average age, 64.1 yr) in the S' <11.8 cm/s group and 53 patients (11 males and 42 females; average age, 64 yr) in the S' ≥ 11.8 cm/s group. There were no significant differences in sex ($P=0.985$) and age (1.000) between the two groups. The S' <11.8 cm/s group showed a significantly larger TK (28.3° *vs.* 19.4°) preoperatively ($P=0.013$) (Table 4), and lower TA and larger TA–SVA (7.8 *vs.* 9.4 and 2.8 mm *vs.* –27.2) postoperatively ($P=0.019$ and 0.010; Table 5). Other parameters showed no significant differences between the S' <11.8 and ≥ 11.8 cm/s groups preoperatively and postoperatively (Table 4 and 5).

Multivariate logistic regression analysis showed that the inflection point level (odds ratio = 0.411; 95% CI: 0.199, 0.848; $P=0.016$) and height (odds ratio = 1.115; 95% CI: 1.002, 1.240; $P=0.047$) were significant influential factors for preoperative LVEF < 59.3%. No significant influential factors were identified for TAPSE and S'.

TABLE 4. Preoperative Comparisons

Parameters	LVEF <59.3% (N = 10)	LVEF ≥59.3% (N = 51)	*P*	TAPSE <20 mm (N = 11)	TAPSE ≥20 mm (N = 50)	*P*	S′ <11.8 cm/s (N = 8)	S′ ≥11.8 cm/s (N = 53)	*P*
Age (yr)	58.8 ± 15.3	65.1 ± 14.1	0.211	63.6 ± 17.0	64.1 ± 13.9	0.921	64.1 ± 12.7	64.0 ± 14.7	0.985
Sex			0.397			1.000			1.000
Male	3 (30.0)	9 (11.6)		2 (18.2)	10 (20.0)		1 (12.5)	11 (20.8)	
Female	7 (70.0)	42 (82.4)		9 (81.8)	40 (80.0)		7 (87.5)	42 (79.2)	
Height (cm)	159.8 ± 13.9	150.7 ± 8.3	0.007*	152.7 ± 16.2	152.1 ± 8.1	0.902	154.4 ± 18.0	151.9 ± 8.2	0.505
Weight (kg)	55.6 ± 18.1	54.1 ± 9.9	0.702	54.8 ± 17.2	54.2 ± 10.0	0.891	58.0 ± 19.8	53.8 ± 9.8	0.568
BMI (kg/m^2)	21.3 ± 3.2	23.8 ± 4.0	0.074	23.3 ± 4.8	23.4 ± 3.9	0.939	24.0 ± 4.7	23.3 ± 3.9	0.666
Cobb angle (°)	39.7 ± 25.0	33.4 ± 20.3	0.392	27.8 ± 23.3	35.9 ± 20.5	0.252	31.1 ± 24.4	34.9 ± 20.7	0.636
C7–SVA (mm)	112.3 ± 88.9	96.9 ± 74.5	0.564	126.8 ± 95.5	93.4 ± 71.3	0.191	137.0 ± 98.2	93.7 ± 72.0	0.137
TK (°)	21.3 ± 16.5	21.3 ± 3.2	0.879	21.8 ± 20.5	20.2 ± 16.8	0.787	28.3 ± 6.3	19.4 ± 18.2	0.013*
TLK (°)	15.8 ± 6.1	20. 8 ± 2.9	0.485	24.7 ± 14.2	18.9 ± 21.6	0.402	25.3 ± 15.4	19.2 ± 21.2	0.441
LL (°)	6.3 ± 23.4	13.9 ± 20.4	0.296	14.2 ± 23.5	12.3 ± 20.6	0.794	12.1 ± 19.0	12.8 ± 21.4	0.938
L4–S (°)	17.8 ± 19.1	24.1 ± 15.6	0.265	22.0 ± 15.5	23.3 ± 16.5	0.812	21.5 ± 17.0	23.3 ± 16.3	0.773
PI (°)	49.7 ± 11.0	51.9 ± 9.6	0.528	52.8 ± 10.8	51.2 ± 9.7	0.629	52.4 ± 8.9	51.4 ± 10.0	0.791
SS (°)	13.3 ± 9.6	18.0 ± 11.6	0.236	16.3 ± 13.9	17.5 ± 11.0	0.758	13.9 ± 14.5	17.8 ± 11.0	0.375
PT (°)	36.4 ± 11.9	33.6 ± 10.9	0.505	36.5 ± 10.9	33.5 ± 11.1	0.414	37.0 ± 11.0	33.6 ± 11.1	0.424
PI–LL (°)	43.4 ± 26.8	37.9 ± 20.2	0.422	38.6 ± 24.8	38.9 ± 20.7	0.973	40.3 ± 22.4	38.6 ± 21.3	0.842
TA	4.0 ± 2.5	5.1 ± 3.2	0.553	4.4 ± 3.2	5.1 ± 3.1	0.532	4.6 ± 3.6	5.0 ± 3.0	0.758
TA–SVA (mm)	−11.5 ± 35.9	−8.5 ± 34.1	0.804	−16.5 ± 33.6	−7.4 ± 34.4	0.424	−20.6 ± 27.7	−7.3 ± 34.9	0.306
Inflection point	1.5 ± 0.9	2.9 ± 1.5	0.007*	2.4 ± 1.5	2.8 ± 1.6	0.513	2.1 ± 1.7	2.8 ± 1.5	0.273
Inflection point–SVA (mm)	9.9 ± 12.2	6.3 ± 22.6	0.629	3.9 ± 18.7	7.6 ± 21.8	0.609	1.6 ± 13.2	7.7 ± 22.1	0.455
LA	0.6 ± 0.7	1.0 ± 1.1	0.245	0.7 ± 0.8	1.0 ± 1.1	0.436	0.5 ± 0.7	1.0 ± 1.1	0.245
LA–SVA (mm)	21.2 ± 4.6	22.5 ± 10.8	0.710	21.5 ± 6.5	22.5 ± 10.7	0.788	22.5 ± 4.7	22.3 ± 10.7	0.951
VC (mL)	3484 ± 1476	2644 ± 668	0.109	2925 ± 1563	2751 ± 687	0.725	3013 ± 1764	2747 ± 701	0.686
%VC (%)	103.0 ± 21.9	102.4 ± 19.7	0.929	99.3 ± 24.7	103.2 ± 18.9	0.557	101.6 ± 22.4	102.6 ± 19.8	0.891
FEV1.0% (%)	81.2 ± 10.1	77.3 ± 6.0	0.299	80.8 ± 10.7	77.3 ± 6.0	0.137	82.2 ± 9.8	77.3 ± 6.5	0.066

Continuous data are presented as mean ± SD of median. Categorical data are presented as n (%).

BMI indicates body mass index; FEV1.0%, percent forced expiratory volume in 1 second; LA, lumbar apex; LL, lumbar lordosis; LVEF, left ventricular ejection fraction; PI, pelvic incidence; PT, pelvic tilt; S′, tricuspid annular peak systolic velocity; SS, sacral slope; SVA, sagittal vertical axis; TA, thoracic apex; TAPSE, tricuspid annular plane systolic excursion; TK, thoracic kyphosis; TLK, thoracic lumbar kyphosis; VC, vital capacity.

**Statistically significant.*

TABLE 5. Postoperative Comparisons

Parameters	LVEF <59.3%	LVEF ≥59.3%	*P*	TAPSE <20 mm	TAPSE ≥20 mm	*P*	S′ <11.8 cm/s	S′ ≥11.8 cm/s	*P*
	(n=10)	(n=51)		(n=11)	(n=50)		(n=8)	(n=53)	
Inflection point	4.3±0.6	4.3±1.0	0.895	4.2±0.6	4.4±1.0	0.673	4.1±0.9	4.4±0.9	0.498
	(n=9)	(n=51)		(n=10)	(n=50)		(n=7)	(n=51)	
Cobb angle (°)	43.2±23.7	33.4±20.3	0.197	29.8±23.5	35.9±20.5	0.405	34.4±24.4	34.9±20.7	0.952
C7–SVA (mm)	60.0±79.5	40.9±49.5	0.337	84.1±79.6	35.7±45.0	0.091	81.0±84.1	38.8±48.5	0.238
TK (°)	30.2±11.1	32.0±13.4	0.716	32.2±11.8	31.6±13.4	0.896	35.0±9.0	31.3±13.5	0.482
TLK (°)	9.6±14.3	11.0±10.5	0.720	14.8±13.1	10.0±10.5	0.210	11.4±15.6	10.7±10.5	0.871
LL (°)	38.0±13.8	42.7±11.5	0.262	38.4±13.2	42.4±11.7	0.336	35.1±14.0	42.6±11.5	0.120
L4–S (°)	30.0±12.6	27.8±10.6	0.571	30.8±10.1	27.7±11.2	0.419	32.0±10.5	27.7±11.0	0.336
PI (°)	51.3±11.9	52.1±9.6	0.827	51.7±9.7	51.7±10.0	1.000	51.3±7.4	51.8±10.2	0.907
SS (°)	29.3±6.9	31.9±9.3	0.425	31.9±7.0	31.5±9.3	0.894	31.0±9.0	31.6±9.0	0.864
PT (°)	20.3±11.2	20.1±10.3	0.954	19.8±7.2	20.2±10.9	0.908	20.3±8.9	20.1±10.6	0.971
PI–LL (°)	13.0±12.9	9.4±13.0	0.236	13.3±10.8	9.3±13.3	0.373	16.1±12.6	9.1±12.8	0.179
TA	8.0±2.5	5.1±3.2	0.447	8.1±2.3	9.5±1.6	0.024*	7.8±2.6	9.4±1.6	0.019*
TA–SVA (mm)	−15.9±33.4	−25.1±28.6	0.388	−14.5±27.3	−25.6±29.5	0.279	2.8±32.2	−27.2±27.3	0.010*
Inflection point–SVA (mm)	4.3±0.6	4.3±1.0	0.551	6.0±15.5	3.2±19.8	0.678	10.7±13.4	2.8±19.6	0.304
LA	1.4±0.5	1.7±0.8	0.146	1.5±0.6	1.7±0.8	0.394	1.6±0.5	1.7±0.8	0.664
LA–SVA (mm)	25.9±5.8	28.0±10.3	0.552	24.1±3.6	28.4±10.4	0.204	25.7±4.3	27.9±10.2	0.572
	(n=10)	(n=46)		(n=11)	(n=45)		(n=8)	(n=48)	
VC (mL)	2752±1359	2239±585	0.270	2271±1222	2345±661	0.849	2530±1311	2298±681	0.445
%VC (%)	83.6±27.4	85.2±19.5	0.822	77.2±23.4	86.8±20.0	0.173	86.6±18.7	84.6±21.4	0.807
FEV1.0% (%)	81.4±7.4	78.7±8.1	0.337	82.1±8.4	78.5±7.8	0.176	81.0±7.4	78.9±8.1	0.490

Data are presented as mean ± SD of median.

BMI indicates body mass index; FEV1.0%, percent forced expiratory volume in 1 second; LA, lumbar apex; LL, lumbar lordosis; LVEF, left ventricular ejection fraction; PI, pelvic incidence; PT, pelvic tilt; S′, tricuspid annular peak systolic velocity; SS, sacral slope; SVA, sagittal vertical axis; TA, thoracic apex; TAPSE, tricuspid annular plane systolic excursion; TK, thoracic kyphosis; TLK, thoracic lumbar kyphosis; VC, vital capacity.

**Statistically significant.*

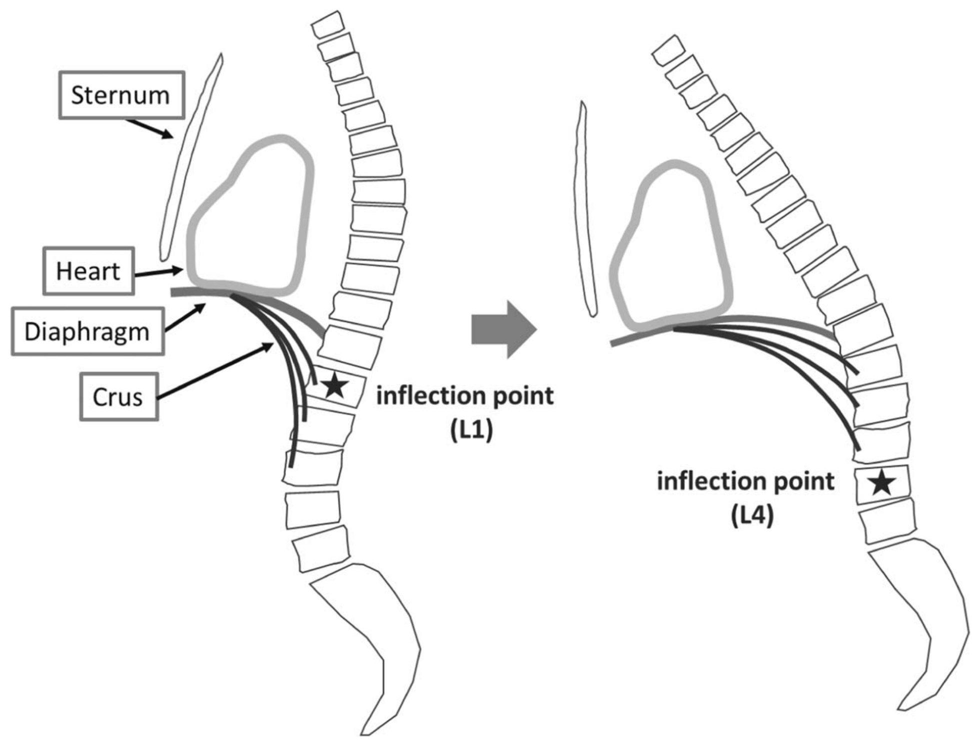

Figure 6. Schema of the extended diaphragm in the lower inflection point in a case of adult spinal deformity. The left side schema represents a normal case. The right side schema represents the lower inflection point in a case of spinal kyphosis.

DISCUSSION

This is the first report of perioperative echocardiographic evaluation in patients undergoing corrective fusion surgery for ASD. Perioperative cardiac function did not deteriorate postoperatively. Moreover, in those with lower cardiac function preoperatively, there were significant improvements noted postoperatively.

Huh *et al*[29] performed echocardiographic evaluations in patients with AIS without surgical treatment. Thoracic dominant scoliosis was correlated with cardiac function compared with lumbar dominant scoliosis. A larger Cobb angle was significantly correlated with myocardial diastolic dysfunction, and this was attributed to restrictive lung capacity and pulmonary venous return impairment. Li *et al*[30] also reported that left ventricular mechanics were impaired in patients with idiopathic scoliosis with a median Cobb angle of 75°. They suggested that impaired left ventricular systolic and early diastolic myocardial deformation might be caused by the curvature of the spine. They also reported impaired left ventricular diastolic dysfunction in patients with congenital scoliosis with a median Cobb angle of 61°.[33] They suggested that a decrease in the volume of the thoracic cavity due to the compression of pliable structures by the spinal curvature could influence cardiopulmonary function. Liu *et al*[38] reported structural heart abnormalities in 14 of 80 patients undergoing surgery for AIS: atrial septal defect (n = 7), ventricular septal defect (n = 3), mitral valve dysplasia (n = 2), patent ductus arteriosus (n = 1), and Eustachian valve remnant (n = 1). Functional abnormality (n = 11); tricuspid regurgitation (n = 9), trace mitral regurgitation (n = 1), and pericardial effusion (n = 1), were also detected.

Some of these findings in AIS could be applied to ASD, especially in adult idiopathic scoliosis cases. However, considering that the most common pathology of ASD is degenerative kyphoscoliosis from the lower thoracic to the lumbar region, the impact of such deformities on the heart would be different. Indeed, this study found no significant correlations between cardiac functions and Cobb angle as the coronal parameter (Tables 4 and 5). Therefore, evaluations of cardiac function in patients with ASD are crucial. In this study, the cardiac function represented by LVEF did not deteriorate postoperatively and improved in cases of lower preoperative LVEF. Interestingly, the inflection point level was significantly lower in the LVEF <59.3% cases, and other radiographic parameters were not different between the two groups preoperatively. Moreover, this preoperative difference in inflection point level disappeared postoperatively.

The mechanism behind this was thought to include not only radiographic aspects but also anatomic and functional aspects. The average inflection point level in older volunteers was around L1 and L2.[34] In the current study, the average preoperative inflection point level was around L4 in the LVEF <59.3% group. Considering that the crux of the diaphragm arises from L1 to L3,[39,40] the crux may extend posteriorly in the lower inflection point cases due to spinal kyphosis (Figure 6). Consequently, the mobility of the diaphragm would be impaired. Indeed, Ciloglu *et al*[41] reported that the diaphragm became thinner and softer at end-inspiration in cases of spinal hyperkyphosis. Moreover, the imposition of negative intrathoracic pressure, caused by diaphragm dysfunction,[42] resulted in a reduction in LVEF.[43]

In contrast, spinal hyperkyphosis reduces the amount of space in the chest, mobility of the rib cage, and expansion of the lungs. Therefore, greater kyphosis may lead to more severe pulmonary impairment.[44] In this study, larger TK was correlated with lower S'. Cardiac function is closely correlated with lung function,[45] and spinal kyphosis might be correlated with right ventricular contractility.

Sansur *et al*[46] reported 669 complications [including 7 (1%) cardiac and 43 (6.4%) pulmonary complications] in 4980 adult scoliosis cases. In our series, Yoshida *et al*[47] reported 86 major perioperative complications, including 1 (1.2%) respiratory and 2 (2.3%) cardiac complications, in 304 patients undergoing surgery for ASD. Cardiopulmonary complication rates in our series tended to be lower than those of other reports. Planned two-stage surgery has been performed in patients with ASD since 2014 in our institution.[8] This divided surgical intervention could be the reason for fewer cardiopulmonary complications. In fact, no cardiac complications occurred in this study. One (1.6%) atelectasis case was observed as a respiratory complication without any treatment.

This study has some limitations. First, the sample size was small, although the required sample size of 54 was achieved. The primary outcome used for the sample size calculation—LVEF—did not change significantly after surgery. Therefore, the comparisons between the two groups were performed as subanalyses; however, these sample sizes were inadequate with insufficient statistical power to detect significant between-group differences. A larger sample size is required to confidently examine the relationship between ASD and cardiac function. Second, this study was evaluated in the acute perioperative phase. Thus, long-term follow-up is needed in the future. Third, one patient with a low preoperative LVEF (52%) could not stand at 2 weeks postoperatively. Since we performed supine whole spine radiography 2 weeks postoperatively (Figure 4), we only measured the inflection point as a postoperative radiographic parameter in this patient. Fourth, five cases of patients under 40 years old were included in this study [three cases of patients aged 22 yr (one male, two females), one case of a 28-yr-old female, and one case of a 32-yr-old female]. These cases were all adult idiopathic scoliosis with mainly coronal deformity. Considering that the main pathology of ASD was sagittal deformity, patients aged less than 40 years should be excluded from future work.

CONCLUSIONS

Perioperative cardiac function did not deteriorate after surgery in patients with ASD. In those with lower cardiac function preoperatively, there were significant improvements noted postoperatively. The inflection point level was significantly lower in the group with a lower preoperative LVEF. TK was significantly larger in the group with a lower preoperative tricuspid annular peak systolic velocity. These findings should prove helpful to spine surgeons in planning ASD interventions and in preoperative counseling.

➢ Key Points

- ❑ Perioperative cardiac function did not deteriorate after corrective fusion surgery in patients with ASD.
- ❑ In lower preoperative LVEF, TAPSE, and S′ groups, LVEF, TAPSE, and S′, respectively, increased significantly postoperatively.
- ❑ The preoperative inflection point level was significantly lower in the lower LVEF group.
- ❑ Preoperative TK was significantly larger in the lower S′ group.

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