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Clinical Studies

Impact of pleural effusion at an early period after posterior spinal fusion for adolescent idiopathic scoliosis on future pulmonary function and lung volume

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A R T I C L E I N F O

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A B S T R A C T

Background: Posterior spinal fusion (PSF) for adolescent idiopathic scoliosis (AIS) has a potential risk for postoperative pleural effusion. Although pleural effusion at an early period after PSF for AIS occurs with a relatively high frequency and occasionally requires some treatments, the impact of postoperative pleural effusion on future pulmonary function or lung volume (LV) has not been clarified to date. The aim of this study was to evaluate the effect of pleural effusion after PSF for AIS on the postoperative pulmonary function and LV.
Methods: A total of 114 consecutive patients who underwent PSF for AIS followed up greater than 2 years at our institute were retrospectively reviewed. We evaluated postoperative pleural effusion by computed tomography (CT) at the 1-week follow-up and divided patients into the pleural effusion (PF) and non-pleural effusion (NP) groups. We investigated spirometry parameters recorded for testing included vital capacity (VC), forced expiratory volume in the first second (FEV1), %VC, and FEV1% and measured the LV using CT images and a workstation at baseline and 2 years after surgery.
Results: A total of 87 (76.3%) patients with postoperative pleural effusion were identified, but all patients were asymptomatic and did not require additional treatment for postoperative pleural effusion. All pulmonary function parameters at the 2-year follow-up exhibited no significant differences between the two groups. Although preoperative left LV (1.21±0.30 L vs. 1.36±0.34 L; p=.022) and total LV (2.68±0.62 L vs. 2.99±0.73 L; p=.031) were significantly lower in the PF group than in the NP group, all postoperative LV parameters were similar between the two groups.
Conclusions: Pleural effusion at an early period after PSF for AIS was a postoperative occurrence without an impact on future pulmonary function and LV.

Introduction

The pulmonary function in patients with adolescent idiopathic scoliosis (AIS) deteriorates with the progression of scoliosis [1]. Therefore, preventing the deterioration of the pulmonary function is one of the important purposes of corrective surgery for AIS [2]. Although posterior spinal fusion (PSF) has demonstrated stable surgical outcomes as a standard treatment procedure for AIS [3–5], whether PSF improves postoperative pulmonary function is currently controversial [6–8]. The patients with AIS are initially assessed in children who are often too young to cooperate with the protocol of spirometry [9]. Although recent studies have measured the change in lung volume (LV) after PSF as

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a more accurate index of respiratory function in this population, these results have also been as inconsistent as the change of pulmonary function after PSF [10–12].

PSF for AIS has a potential risk for postoperative pleural effusion [13–18]. Previous reports have shown that the frequency of pleural effusion after PSF for AIS may vary depending on the tool or timing of pleural effusion detection and ranged from 0.84% to 71% [14–17]. Several studies have reported cases in which respiratory function was impaired due to pleural effusion and required such treatments as thoracocentesis and chest tube placement [13,14]. Hayashi et al. [15] investigated the frequency of pleural effusion after PSF for AIS using computed tomography (CT) performed at 1 week after surgery and found that it occurred with a relatively high probability of 71%.

Although pleural effusion at an early period after PSF for AIS occurs with a relatively high frequency and occasionally requires some treatments, the impact of postoperative pleural effusion on future pulmonary function or LV has not been clarified to date. The purpose of this study is to examine the effect of pleural effusion at an early period after PSF for AIS on the postoperative pulmonary function and LV. We hypothesized that postoperative pleural effusion after PSF for AIS would not affect future pulmonary function and LV.

Materials and methods

Study participants

We retrospectively reviewed the prospectively enrolled consecutive AIS patients (aged 10–19 years) who underwent PSF at our institution between 2006 and 2014. All patients had completed CT examination preoperatively (at baseline), 1 week and 2 years after surgery and pulmonary function test (PFT) at baseline and 2 years after surgery. All patients got out of bed within 2 days after surgery and did not need prolonged bed rest. After excluding the patients with a Lenke type 5 curve due to the absence of a thoracic structural curve, 114 patients (female: 104, male: 10) were included in this study. Among 114 patients with AIS, the distribution of Lenke classification was as follows: type 1, 68; type 2, 20; type 3, 7; type 4, 4; type 6, 15 patients. This research was approved by our institution's review board, and the approved number was 20090042. We obtained written informed consent for the use of patient data from each patient or their guardian, according to the institution's ethical guidelines.

Surgical procedure

All surgeries were performed under general anesthesia and neuromonitoring. After meticulous exposures of posterior elements following a medial skin incision, pedicle screws (PSs) were placed bilaterally at almost every vertebra within the fusion area, occasionally skipping some using a free-hand technique. A specially designed ball tip probe that consists of a ball-shaped metal tip with a flexible metal shaft was used to make a guide hole through the pedicle into the vertebral body [19]. After applying rods, a gradual correction was done under neuro-monitoring.

Radiographic parameters

The following radiographic data were recorded from standing full-length spine radiographs at baseline and 2 years after surgery: The Cobb angle of the proximal thoracic (PT) curve, main thoracic (MT) curve, and thoracolumbar/lumbar (TL/L) curve; the postoperative correction angle of the Cobb angles of PT, MT, and TL/L; the correction rates of the Cobb angles of MT, T2-4 kyphosis, T5-12 kyphosis, and lumbar lordosis (LL); and the postoperative correction angles of T2-4 kyphosis, T5-12 kyphosis, and LL.

Pulmonary function testing

Pulmonary function test was performed using spirometry according to the Japanese Respiratory Society guidelines at baseline and 2 years after surgery [20]. Spirometry parameters recorded for testing included vital capacity (VC), forced expiratory volume in the first second (FEV1), %VC (normalized to the patients' age, sex, height, or arm span-matched standards), and FEV1% (the ratio of FEV1 to forced VC).

Computed tomography

Low-dose CT examinations were performed using a 16-, 64-, or 320-detector CT scanner. Slice thickness was set at 1 mm or 1.25 mm. The effective dose estimate for CT was 4.1±0.9 mSv, which was determined by the dose length product measurements and appropriate normalized coefficients reported in the literature [21]. A pleural effusion was measured as fluid collection in the dorsal thoracic cavity on axial CT images at 1 week and 2 years after surgery. Hayashi et al. [15] defined a depth of fluid collection greater than 3 mm as a positive finding of pleural effusion. However, we could not distinguish between pleural effusion and the thickening of the pleura at a depth of 3 mm. Thus, we defined positive pleural effusion as a fluid collection depth of 5 mm or above. We divided the patients into the pleural effusion (PF) and nonpleural effusion (NP) groups based on the presence or absence of the pleural effusion at the 1-week follow-up. We initially hypothesized that the accidental insertion of PSs into the thoracic cavity would cause pleural effusion. Therefore, we investigated the frequency of perforations caused by the insertion of PSs at the lateral wall of the pedicle and lateral and anterior wall of the vertebra using postoperative CT images. We defined >2 mm of deviation as a positive finding of pedicle or vertebral perforation [22]. Additionally, LV values were measured on CT images by an experienced radiologist, as previously described [23]. Briefly, the axial CT images of the lungs were extracted from the axial CT images of the trunk, followed by 3-dimentional (3D) volumetric lung reconstruction using a workstation (Advantage Workstation 4.6, GE Healthcare) before the operation and 2 years after surgery. We measured the right lung volume (RLV) and left lung volume (LLV) and calculated total lung volume (TLV).

Data collection

Complete preoperative and 2-year follow-up data on coronal and sagittal radiographic parameters, PFT parameters, and LV parameters were available on all patients. Additionally, the following data were collected on each patient: age, sex, height, body mass index (BMI), Lenke classification (Supplementary Table 1), Risser grade (Supplementary Table 2), the frequency and number of PS perforations, the number of fused vertebrae in whole spine, thoracic fused vertebrae, and inserted thoracic PSs, operative time, and intraoperative blood loss, infusion, and transfusion.

Statistical analysis

Data were presented as the mean and standard deviation for continuous variables and number (percentages) for categorical variables. Differences between the PF and NP groups were evaluated using Pearson's chi-square test, Fisher's exact test, Student's *t* test, Mann–Whitney *U*-test, and Wilcoxon signed-rank test in the univariable analyses. Then, we applied a Poisson regression model to identify the predictive factors that independently associated with pleural effusion after PSF for AIS. In this multivariable model, the outcome variable was the depth of fluid correction of more than 5 mm at the dorsal thoracic cavity on axial CT images, and the independent variables as age, sex, and variables with $p<.1$ in the univariable analyses. The variables with high correlation coefficient (> 0.50) were excluded from the multivariable model because they were considered to have multicollinearity. The risk ratio (RR) and

Table 1
Demographic characteristics of the patients.

		PF (n=87)	NP (n=27)	p value*
Age	years	14.7 ± 2.1	15.1 ± 2.1	0.463
Sex	male : female	6:81	4:23	0.185
	% male	6.9%	14.8%	
Height	cm	157 ± 7.2	157.1 ± 6.4	0.801
BMI	kg/m^2	18.3 ± 2.6	18.4 ±1.8	0.582
Lenke type	type 1	53 (60.9%)	15 (55.6%)	0.718
	type 2	15 (17.2%)	5 (18.5%)	
	type 3	5 (5.7%)	2 (7.4%)	
	type 4	2 (2.3%)	2 (7.4%)	
	type 6	12 (13.8%)	3 (11.1%)	
Risser grade		3.3 ± 1.5	3.7 ± 1.1	0.270

BMI, body mass index.
* t-test, Mann–Whitney U test, or Fisher's exact test.

Table 2
Comparison of operative factors between PF and NP group.

	PF (n=87)	NP (n=27)	p value*
Fused vertebrae	10.0 ± 2.0	9.8 ± 2.3	.630
Thoracic fused vertebrae	8.4 ± 1.5	8.3 ± 1.9	.412
Thoracic PS	15.1 ± 2.5	14.5 ± 2.7	.421
PS perforation (frequency)	66 (75.9%)	17 (63.0%)	.188
PS perforation (number)	1.8 ± 1.6	1.3 ± 1.3	.168
Operative time (min)	158 ± 53	156 ± 49	.870
Blood loss (mL)	455 ± 296	405 ± 247	.289
Infusion (mL)	2252 ± 965	2125 ± 1067	.426
Transfusion (mL)	277 ± 317	239 ± 145	.855

PS, pedicle screw.
* Mann–Whitney *U* test, or χ^2 test.

Table 3
Comparison of the radiographic parameters between PF and NP group.

		PF (n=87)	NP (n=27)	p value*
Coronal	PT (°)	28.8 ± 9.3	25.9 ± 8.5	.150
	MT (°)	56.7 ± 9.8	50.0 ± 9.6	**.002**
	TL/L (°)	35.1 ± 13.2	30.2 ± 13.9	.137
	ΔPT (°)	14.9 ± 9.1	12.5 ± 8.7	.260
	ΔMT (°)	39.4 ± 10.3	32.7 ± 8.1	**.004**
	ΔTL/L (°)	25.3 ± 11.9	18.9 ± 12.9	**.005**
Correction rate of cobb angle (%)		69.4 ± 12.2	66.2 ± 15.2	.327
Sagittal	T2-4(°)	7.0 ± 5.0	6.6 ± 5.7	.801
	T5-12(°)	15.8 ± 10.4	12.1 ± 10.8	.050
	LL(°)	49.0 ± 8.0	46.3 ± 10.7	.172
	ΔT2-4(°)	−0.9 ± 5.9	-1.9 ± 7.5	.851
	ΔT5-12(°)	−0.6 ± 10.0	-5.5 ± 11.7	.060
	ΔLL(°)	0.5 ± 9.1	-2.4 ± 9.3	.185

PT, proximal thoracic cobb angle; MT, main thoracic cobb angle; TL/L, thoracolumbar/lumbar cobb angle; LL, lumbar lordosis.
* t test or Mann–Whitney *U* test.

95% confidence interval (CI) of each predictive factor were estimated. Multivariable regression analysis was performed using STATA 16 software (Stata Corporation). A p value <.05 was considered statistically significant.

Results

Characteristics of patients with postoperative pleural effusion

The PF and NP groups consisted of 87 (76.3%) and 27 (23.7%) patients, respectively. Pleural effusion accumulated bilaterally in 55 patients (63%), only in the right thorax in 26 patients (30%), and only in the left thorax in 9 patients (7%). All patients in this study had right convex in main thoracic curve, pleural effusion tended to accumulate more on the convex side. The depth of pleura effusion greater than 10 mm was observed in 37 (43%) of 87 patients. All patients in the PF group were asymptomatic and did not require any treatment for pleural effusion. None of the patients had residual pleural effusion at 2-year follow-up. The baseline characteristics (mean age, sex ratio, mean height, mean BMI, the distribution of Lenke classification, and mean Risser grade) were comparable between the 2 groups (Table 1).

The number of fused vertebrae and inserted thoracic PSs, the frequency and number of PS perforations, perioperative factors (operative time, blood loss, infusion, and transfusion) did not differ significantly between the two groups (Table 2).

Radiographic parameters

The MT Cobb angle at baseline (56.7°±9.8° vs. 50.0°±9.6°; p=.002) and the correction angles of MT (39.4°±10.3° vs. 32.7°±8.1°; p=.004) and TL/L Cobb angle (25.3°±11.9° vs. 18.9°±12.9°; p=.005) from baseline to 2-year follow-up were significantly greater in the PF group than in the NP group (Table 3). Other coronal and sagittal radiographic parameters did not differ significantly between the two groups (Table 3).

FT parameters

Table 4 shows the pre- and postoperative PFT parameters. No differences were noted in the preoperative VC, %VC, FEV1, and FEV1% (Table 4). Postoperative VC, FEV1, and FEV1% at 2-year follow-up were significantly improved compared with these preoperative parameters in the two groups (Table 4). On the other hand, postoperative %VC were significantly deteriorated compared with preoperative %VC in the PF group (80.1±15.9 vs. 78.1±15.3; p=.039), but not in the NP group (Table 4). All postoperative PFT parameters exhibited no significant differences between the 2 groups (Table 4).

LV parameters

Although preoperative LLV (1.21±0.30 L vs. 1.36±0.34 L; p=.022) and TLV (2.68±0.62 L vs. 2.99±0.73 L; p=.031) were significantly lower in the PF group than in the NP group, all postoperative LV parameters were similar between the two groups (Table 5). While postoperative LLV and TLV were significantly improved compared with preoperative LLV (1.21±0.30 L vs. 1.27±0.32 L; p=.011) and TLV (2.68±0.62 L vs. 2.78±0.64 L; p=.034) in the PF group, there was no significant difference in the NP group. Regarding RLV, there were no significant differences between pre- and postoperative RLV in both groups (Table 5).

Table 4
Comparison of pre- and post-operative PFT parameters.

	Preoperative			Postoperative			Preoperative vs. Postoperative p value**	
	PF (n=87)	NP (n=27)	p value*	PF (n=87)	NP (n=27)	p value*	PF	NP
VC(L)	2.52 ± 0.52	2.57 ± 0.63	.681	2.69 ± 0.56	2.73 ± 0.54	0.779	**<.001**	**.024**
%VC	80.1 ± 15.9	78.6 ± 17.1	.660	78.1 ± 15.3	75.9 ± 11.9	0.058	**.039**	.242
FEV1(L)	2.11 ± 0.48	2.21 ± 0.57	.394	2.36 ± 0.49	2.44 ± 0.48	0.480	**<.001**	**<.001**
FEV1%	85.4 ± 7.9	86.5 ± 7.1	.556	88.5 ± 6.3	90.9 ± 5.1	0.084	**<.001**	**<.001**

PFT: pulmonary function testing; VC: vital capacity; FEV: forced expiratory volume in the first second
* t-test or Mann–Whitney U test
† t-test or Wilcoxon signed-rank test

Table 5
Comparison of pre- and post-operative LV parameters.

	Preoperative			Postoperative			Preoperative vs. Postoperative p value†	
	PF (n=87)	NP (n=27)	p value*	PF (n=87)	NP (n=27)	p value*	PF	NP
RLV(L)	1.47 ± 0.35	1.63 ± 0.40	0.054	1.51 ± 0.34	1.61 ± 0.37	0.189	.126	.670
LLV(L)	1.21 ± 0.30	1.36 ± 0.34	**0.022**	1.27 ± 0.32	1.36 ± 0.33	0.196	**.011**	.990
TLV(L)	2.68 ± 0.62	2.99 ± 0.73	**0.031**	2.78 ± 0.64	2.98 ± 0.69	0.183	**.034**	.817

LV, lung volume; RLV, right lung volume; LLV, left lung volume; TLV, total lung volume.
* *t* test.
† *t* test.

Table 6
Multivariable regression analysis for pleural effusion

		Multi-variable adjusted risk ratio (RR)	95% CI	p value
Age	11–15y	Ref		
	16–19y	0.946	0.776–1.153	.580
Sex	women	Ref		
	men	0.861	0.540–1.373	.529
△MT (°) per 10° increase		**1.200**	**1.048–1.256**	**<.01**
△TL/L (°) per 10° increase		1.054	0.972–1.143	.205
TLV(L) per 1L increase		**0.840**	**0.710–0.994**	**.042**

Multivariable analysis of predictive factors for pleural effusion after PSF for AIS

In the univariable analyses, the p values of MT Cobb angle at baseline, correction angles of MT and TL/L Cobb angle from baseline to 2-year follow-up, and LLV and TLV at baseline were less than .05. Because the correlation coefficient between the MT Cobb angle at baseline and the correction angle of MT Cobb angle from baseline to 2-year follow-up (r=0.687 from Spearman's rank correlation coefficient) and LLV and TLV at baseline (r=0.962 from Pearson's correlation coefficient) was relatively high, we excluded the preoperative MT Cobb angle and LLV from independent variables of multivariable regression model. After adjusting for age and sex ratio, the correction angle of MT Cobb angle per 10 increase (RR: 1.200, 95% CI: 1.048–1.256, p<.01) and the TLV at baseline per 1L increase (RR: 0.840, 95% CI: 0.710–0.994, p=.042) were identified as independent predictive factors for pleural effusion after PSF for AIS (Table 6).

Discussion

The present study showed that pleural effusion was observed in 76% of patients who underwent PSF for AIS using CT performed at 1 week after surgery. However, all cases were asymptomatic and did not require additional treatment for postoperative pleural effusion. Pleural effusion at 1 week after surgery did not affect pulmonary function or LV at 2-years follow-up, which indicated that pleural effusion at an early period after PSF for AIS was a postoperative occurrence without an impact on pulmonary function. Multivariable analysis identified the larger MT Cobb angle correction and the lower preoperative TLV as independent factors for postoperative pleural effusion in the patients who underwent PSF for AIS, suggesting that the indirect factors due to the correction of scoliosis, rather than direct invasion such as PS perforation, associated with the postoperative pleural effusion. This study is the first report to analyze the impact of pleural effusion after PSF for AIS on postoperative pulmonary function and LV.

Previous studies have demonstrated the therapeutic effect of PSF for AIS on postoperative pulmonary function. Akazawa et al.[6] investigated 47 patients with AIS and reported that PSF with or without thoracoplasty improved postoperative pulmonary function 5 years or later after surgery. Conversely, Byun et al.[7] assessed 35 patients with main thoracic AIS treated with a long-term follow-up > 10 years and showed the postoperative pulmonary function test value was similar to preoperative measurements. Kato et al. [8] also reported PSF for mild to moderate AIS patients and showed no significant improvement of postoperative pulmonary function as a result of systematic review and meta-analysis. Against the background of these controversies, we evaluated preoperative and postoperative pulmonary function by focusing on pleural effusion at an early postoperative period. As a result, although the PFT parameters except for %VC were markedly improved postoperatively, preoperative pulmonary function was not correlated with postoperative pleural effusion, and there was no significant effect of pleural effusion at an early postoperative period on pulmonary function at 2-year follow-up. Postoperative decrease of %VC may be attributed to increased height due to surgical correction and natural growth depending on the patient's age.

Several studies have examined the impact of PSF for scoliosis on the postoperative change in LV. Fu et al. [12] evaluated the operative changes in lung morphology and LV in AIS using 3D CT and 3D reconstruction software and reported that the lung height increased and the thoracic symmetry was improved, whereas the LV did not change postoperatively in the short term. Sarawahi et al. [10] also reported that the surgical correction of AIS improved the thoracic symmetry but did not alter LV postoperatively. Our results indicated that preoperative LLV and TLV were significantly lower and significantly increased postoperatively in the PF group compared with the NP group. On the other hand, all LV parameters did not change from baseline to 2-year follow-up in the NP group. Consequently, all postoperative LV parameters were comparable between the two groups. Since pleural effusion was more frequently accumulated in the right thorax, the exact cause of low preoperative LLV in the PF group remains unclear. However, we believe that there would be a high correlation between the LLV or changes in LLV and pleural effusion. In addition, the analysis of each case revealed that the change in LV from baseline to 2-year follow-up either increased or decreased, with various patterns of change observed depending on the case. The change in TLV from baseline to 2-year follow-up was significantly negatively correlated with the TLV at baseline ($r=-0.33$; $p<.001$) (Supplementary Fig. 1), which suggested that the lower the preoperative LV, the larger the increase in postoperative LV. Therefore, we presume that the LV remains unchanged immediately after surgery but may increase at some point up to 2 years after surgery.

Other previous studies have already shown risk factors for pulmonary complications after surgery for scoliosis. Wang et al. [18] performed a multivariable analysis of postoperative pulmonary complications following posterior instrumentation and fusion for patients diagnosed with nondegenerative scoliosis and found that a preoperative Cobb angle greater than 75°, preoperative respiratory disease, revision surgery, and thoracoplasty were risk factors for postoperative pulmonary complications. Hayashi et al. [15] reported 11 or more fused levels as an independent risk factor for pleural effusion after surgery for AIS. Conversely, our results showed that there was no significant difference in the number of fused levels between the two groups. This discrepancy with our results might be due to the difference in the number of analyzed subjects between the 2 studies (114 in our study versus 58 in the Hayashi et al. [15] study). The mean MT Cobb angle at baseline in the PF and NP groups did not differ substantially between the 2 studies (with pleural effusion 56.7° and without pleural effusion 50.0° [p=.002] in our study vs. with pleural effusion 56.8° and without pleural effusion 52.1° [p= .11] in the Hayashi et al. [15] study). In the present study, although only 5 out of 114 patients had a preoperative MT cobb angle greater than 75°, we identified the larger MT Cobb angle correction and the lower preoperative TLV as potential risk factors for postoperative pleural effusion for AIS, suggesting that pleural effusion accumulated in patients with severe scoliosis who required large corrections and had low preoperative LV.

This study has several limitations. First, our data were collected from a single institution, so further studies in other populations are needed to confirm our findings. Second, the LV and the volume of the thorax or thoracic cavity were not measured at multiple time points and over time during the follow-up period. Thus, we could not identify when the LV changed during the 2 years after surgery. Third, we defined a depth of fluid correction greater than 5 mm on CT images as positive pleural effusion because it was difficult to distinguish between pleural effusion and the thickening of the pleura at a depth of 3mm reported by Hayashi et al. [15]. However, we did not investigate the precise volume and characteristics of pleural effusion by thoracocentesis because all patients were asymptomatic for pleural effusion. Therefore, the patients with thickening of the pleura rather than pleural effusion might be included in the positive pleural effusion group. The prevalence of pleural effusion varies by the definition of "pleural effusion." Whereas Liang et al. [17] investigated pleural effusion using medical records and chest X-ray films and reported the prevalence of pleural effusion after spinal deformity correction surgery was 0.84%, the present study and the report by Hayashi et al. [15] assessed pleural effusion using CT images at 1 week after surgery and indicated the prevalence of more than 70%. We believe that the evaluation method for pleural effusion should be standardized in the future. Fourth, we could not investigate serum albumin level, which may be associated with postoperative pleural effusion, due to the lack of routine evaluation in postoperative blood tests. Fifth, 88% of the subjects in this study were female. The results of this study may apply only to female-dominated populations. Additionally, as reported previously, we do not currently perform a routine assessment for pleural effusion and LV using CT in consideration of radiation exposure [22]. Nevertheless, the present study clarified the effect of pleural effusion after PSF for AIS on postoperative pulmonary function and LV.

In conclusion, pleural effusion at an early period after PSF for AIS occurred relatively frequently at a rate of 76.3% and was potentially correlated to the degree of correction of MT cobb angle and preoperative low LV. However, since all cases were asymptomatic and did not affect future pulmonary function and LV, observation without treatment was considered appropriate in the clinical setting.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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