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Effects of concave thoracoplasty on chest circumference and ventilatory function in adolescence with idiopathic scoliosis

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Abstract

Introduction. Adolescent idiopathic scoliosis (AIS) can reduce rib cage volume, which mechanically overloads the respiratory musculature. A current study examines the influences of concave thoracoplasty on pulmonary function and chest circumference.
Methods. This study included thirty AIS patients of both genders, aged 12 to 18 years, who had a concave thoracoplasty with posterior correction. Pulmonary function, Cobb angles, and chest circumferences were measured before surgery, on the fifth day following surgery, and at three months.
Results. A paired *t*-test was used to compare Cobb angles and chest expansion before and after intervention in the AIS-studied group. The statistical analysis stated that there was a significant decrease in Cobb angles and chest expansion ($p < 0.05$) at post-intervention follow-ups compared to pre-intervention measurements with a change percentage of 56.13% and 18.90%, respectively. Bonferroni correction test was employed to evaluate a pairwise intervention for outcome variables that revealed there were insignificantly increases in vital capacity (VC), forced vital capacity (FVC), and maximal voluntary breathing (MVV) after the intervention compared to before intervention ($p > 0.05$). In contrast, the pairwise comparison test between pre-intervention versus follow-up revealed time effect had significantly increased VC, FVC, and MVV at post-intervention compared to 3 months after the intervention with improvement percentages of 16.51%, 16.11%, and 22.16%, respectively.
Conclusions. Patients with AIS who underwent concave thoracoplasty showed greater improvements in Cobb angles and pulmonary function tests 3 months after surgical intervention. Future research activities should emphasize elucidating areas of confusion to improve care in the AIS.
Key words: adolescent idiopathic scoliosis, concave thoracoplasty, pulmonary function test, chest circumference

Introduction

One of the most frequent spinal deformities is scoliosis. Spinal rotation and lateral movement are the two main characteristics of this condition. Scoliosis is categorized according to whether it affects the thoracic, lumbar, or both regions of the spine [1]. Adolescent idiopathic scoliosis (AIS) is a lateral excess spinal curvature without an exact medical predisposing aetiology [2].

In brief, AIS is a complex multidimensional spinal deformity of the vertebrae, which in severe forms could minimize rib cage capacity, limit rib flexibility, and mechanically overload the respiratory musculature [3]. Therapeutic intervention for scoliosis depends on its severity, where surgical correction via posterior spinal fusion (PSF) is a preventive approach to limit deterioration that could lead to pain, neurologic manifestations, and cardiopulmonary consequences [2].

Scoliosis severity is determined by measuring Cobb angles to evaluate the spinal curvature. If the curve exceeds 50°, a serious lesion requiring immediate repair is needed [1]. The incidence of lung damage in AIS is greater when there is a high degree of thoracic deformation, as seen in cases of severe scoliosis [4].

Clinically, scoliosis is accompanied by limited pulmonary function as a mechanical consequence due to a persistent link between the associated deformed rib cage and efficacy of pulmonary function, which is still unexplained completely. Therefore, therapeutic scoliosis correction improves pulmonary functioning by improving the mechanical efficacy of the respiratory musculature and expanding lung volumes [4].

Since chest wall motion can be measured throughout the breathing process as a functional monitor without actual limiting requirements such as masking and radiation exposure, it is an excellent option to evaluate AIS pulmonary efficacy [5].

Early detection of functional asymmetry in AIS individuals, who manifest clinically with extra functional limitations during preoperative evaluation of congenital forms, ensuring the effectiveness of surgical intervention and its timing [6].

Pulmonary function is critical in treatment decisions for AIS. One of the reasons for surgical intervention is pulmonary impairment caused by spinal deformity [7]. Critical cardiopulmonary functional deterioration is based on restricted chest expansion at the thoracic level in AIS patients, even in mild idiopathic individuals, making it potentially dangerous when curves are severe [8].

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Long-term thoracoplasty effectiveness regarding pulmonary function remains contentious in the current literature as it remarkably falls initially in the early postoperative stage, but then, across recovery, it returns to acceptable physiological values by at least 2 years [9, 10].

A current clinical study recruited thirty hospitalized participants suffering from idiopathic scoliosis. Initial pulmonary function measurements were done by the 5^{th} postoperative day, then three months later. This study allows for a more comprehensive examination of the parameters assessed by the study group. We hypothesized that concave thoracotomy treatment for AIS would enhance pulmonary function and chest expansion.

Subjects and methods

This study used a one-group pre-and post-test design. The current study population included thirty hospitalized participants (14 boys and 16 girls), ages ranging from 12- to 18 years old, suffering from AIS admitted to the El Sallam International Hospital from January to October 2022. After the study participants met the inclusion and exclusion criteria, informed written consent was obtained from the recruited subjects. Participants having a single thoracic curvature with a Cobb angle of more than 40 degrees or a progressive Cobb angle that increases more than 5 degrees at three- and six-month follow-ups were included [1]. The current study excluded double major, triple major, thoracolumbar, and lumbar curves.

Smokers, participants with coexisting conditions that reduce lung function, and those with any condition that interferes with spirometry were not eligible for this study.

While measuring the main curve using Cobb angles, each participant underwent posterior-anterior (PA) radiological assessment from a standing position, while measuring both crossing lines, one drawn at the superior endplate of the upper main thoracic curve vertebra and the other drawn at the inferior endplate of lower main thoracic curve vertebra [11, 12].

All patients who had surgical intervention had concave thoracoplasty and posterior correction performed. Patients were positioned prone on a surgery table after receiving general anaesthesia. A long incision was made along the lower back, and the muscles were cut away to expose the spinal bones. The spinal curve was then straightened with the use of instruments. After ensuring that the implants were in place, the incision was closed. The orthopedist was responsible for the diagnosis of the AIS and all surgical procedures. All patients underwent the same surgical intervention. Because the treatment has low morbidity, it can be considered in patients with cosmetic concerns and severe residual rib hump following primary curve correction.

A palpmeter was used to measure chest expansion. The palpmeter was positioned horizontally at the xiphoid process across the chest for each participant while assuming a standing position. The palpmeter's two limbs moved laterally during inhalation and returned to their original position during expiration, allowing measurements of differences from a scale attached to the limbs.

The patient's weight and height were measured, recorded, and entered into the equipment. Patients were instructed to take a deep breath and then securely close their mouths around the tube before sitting in a chair. Patients were positioned in a seated position in accordance with the guidelines recommended by the American Thoracic Society [13]. Several different exercises were carried out until the patient reached a level of understanding and comfort with the instructions. The patient was instructed to follow the PFT measurement procedures, so they took a deep breath and then exhaled into a spirometer [13]. PFT findings were displayed values in litres on the calibrated spirometer.

Every single subject performed a full spirometry evaluation (Multi-Functional Spirometer HI-801, Japan). Spirometry results were evaluated for all subjects in accordance with the standards for pulmonary function tests. Initially, immediately at the end of the study, and after three months following surgery. Each measurement was repeated 3 times, and the highest reading was selected. The patient's chest was measured in terms of Cobb angles, thoracic circumference, vital capacity (VC), forced vital capacity (FVC), and maximal voluntary breathing (MVV). Spirometry was performed and interpreted by a pediatric pulmonologist. Participants performed routine physical therapy in the form of respiratory training and aerobic exercise on a treadmill or stationary bicycle, with an intensity of training being held between 60% and 80% of the maximum heart rate.

Statistical analysis

SPSS Package software version 25 (SPSS, Inc., Chicago, IL) was used for statistical analysis. Regarding clinical participants' selected quantitative outcome measures, Cobb angles, chest expansion, VC, FVC, and MVV variables were expressed in mean and standard deviation. The AIS study group was compared initially and immediately at the end of the study using a *t*-test to record significant decreases in Cobb angles and chest expansion, where the one-way analysis of variance (ANOVA) test was performed to analyze results of the initial, immediately at the end of the study, and at three-month follow-up. When the *F*-test from the ANOVA test was significant, the Bonferroni correction test (post-hoc test) was employed to evaluate a pairwise intervention for outcome variables. All conducted statistical analyses were accepted at a 0.05 significance level.

Sample size

A calculated sample size of thirty individuals using a significance level (α) = 0.05, 90% power, and effect size (*d*) of 0.6138614, was conducted via statistical G*POWER software (version 3.1.9; Heinrich-Heine-University, Düsseldorf, Germany) for 2-tailed *t*-tests (difference mean from a constant-one sample).

Data collection

Data has been assessed for normality and homogeneity of variances. Regarding normality, the Shapiro–Wilk test verified and reflected data with a normal distribution ($p > 0.05$) by removal of outliers detected via box and whiskers plots. As well, Levene's test regarding variance homogeneity ensured no significant difference ($p > 0.05$). Therefore, the data was normally distributed and parametric analysis was done.

Results

Thirty idiopathic scoliosis participants (13 males and 17 females), their clinical features are shown in Table 1, had a mean ± *SD* (minimum-maximum) age of 16.53 ± 1.04 (15.00–19.00 year), a rib number of 4.10 ± 1.02 (2.00–6.00), a rib level of 7.10 ± 1.45 (3.00–9.00), a weight of 60.63 ± 9.37 (45.00–75.00 kg), a height of 162.67 ± 6.63 (151.00–172.00 cm), and a BMI of 22.91 ± 3.70 (19.74–25.35 kg/m^2) in the study group.

Table 1. General features of the study population

Variable	Mean values (mean ± *SD*)	Minimum value	Maximum value
Age (year)	16.53 ± 1.04	15.00	19.00
Number of ribs	4.10 ± 1.02	2.00	6.00
Level of ribs	7.10 ± 1.45	3.00	9.00
Weight (kg)	60.63 ± 9.37	45.00	75.00
Height (cm)	162.67 ± 6.63	151.00	172.00
BMI (kg/m^2)	22.91 ± 3.70	19.74	25.35

BMI – body mass index

Table 2. Comparison within the study group for Cobb angle and chest expansion

Item	Cobb angle (mean ± *SD*)	Chest expansion (mean ± *SD*)
Pre-intervention	57.67 ± 21.98	3.28 ± 0.67
Post-intervention	25.30 ± 8.31	2.66 ± 0.75
MD (change)	32.37	0.62
95% CI	25.85–38.89	0.54–0.70
Change %	56.13%	18.90%
p-value	0.0001*	0.0001*

MD – mean difference, CI – confidence interval
* significant ($p < 0.05$)

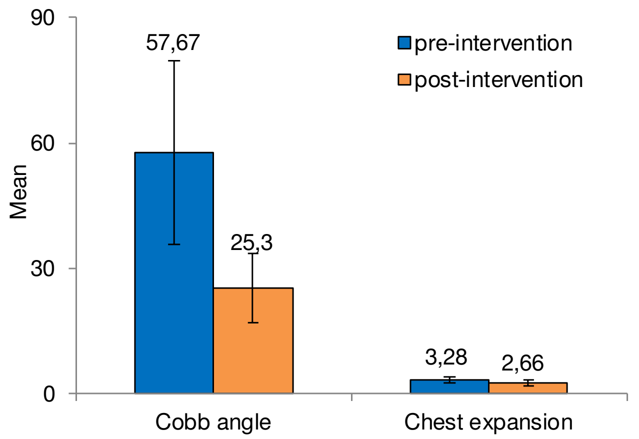


Figure 1. Mean values of initial and at the end of the study for Cobb angle and chest expansion in the AIS population

Comparisons of Cobb angle and chest expansion within the idiopathic scoliosis study group are tabulated in Table 2 and represented in Figure 1. Cobb angle mean ± *SD* values at pre- and post-intervention were 57.67 ± 21.98 and 25.30 ± 8.31, respectively, and 3.28 ± 0.67 and 2.66 ± 0.75, respectively, for chest expansion in the idiopathic scoliosis study group. The statistical analysis revealed that Cobb angle values ($p = 0.0001$) and chest expansion ($p = 0.0001$) were remarkably minimized immediately at the study end in comparison with initial measurement changes by 32.37 and 0.62, respectively, and percentage changes of 56.13% and 18.90%, respectively.

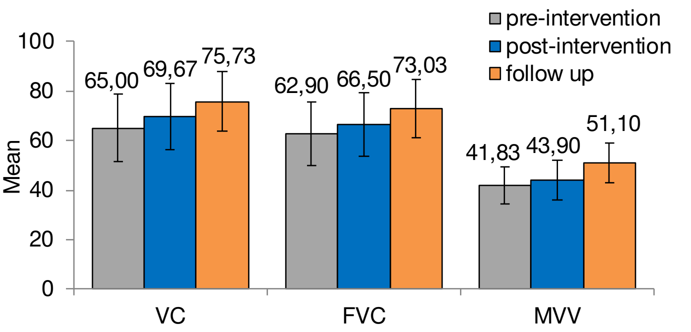
The VC, FVC, and MVV at pre-intervention, post-intervention, and follow-up within the idiopathic scoliosis study group were tabulated in Table 3 and represented in Figure 2. The VC, FVC, and MVV mean values ± *SD* were 65.00 ± 13.68, 69.67 ± 13.53, and 75.73 ± 11.99, respectively; FVC were 62.90 ± 12.94, 66.50 ± 12.67, and 73.03 ± 11.78, respectively, and MVV were 41.83 ± 7.65, 43.90 ± 7.96, and 51.10 ± 8.04, respectively. Remarkable differences were revealed between the initial, immediately at the end of the study, and after three months ($p = 0.008$), FVC ($p = 0.008$), and MVV ($p = 0.0001$).

Bonferroni post-hoc tests for VC, FVC, and MVV within the study group are shown in Table 3. A pairwise comparison test between pre-intervention versus post-intervention revealed there were insignificantly ($p > 0.05$) increases in VC ($p = 0.513$), FVC ($p = 0.800$), and MVV ($p = 0.939$) at post-intervention compared to pre-intervention with change of 4.67, 3.60, and 2.07, respectively and improved percentages of 7.19%, 5.72%, and 4.95%, respectively.

In contrast, the pairwise comparison test between pre-intervention versus follow-up of intervention after 3 months (Table 3) revealed the time effect significantly ($p < 0.05$) increased VC ($p = 0.006$), FVC ($p = 0.007$) and MVV ($p = 0.0001$) at post-intervention compared to after 3-month follow-up with changes of 10.73, 10.13, and 9.27, respectively, and improvement in percentages of 16.51%, 16.11%, and 22.16%, respectively.

There were insignificantly ($p > 0.05$) increases observed between pairwise post-intervention versus 3-month follow-up (Table 3) in both VC ($p = 0.228$) and FVC ($p = 0.137$) by changes of 6.06 and 6.53, respectively, and improvement percentages of 8.70% and 9.82%, respectively, however, a significant ($p < 0.05$) increase in MVV ($p = 0.002$) 3 months after intervention compared to post-intervention with a change of 7.20 and an improvement percentage of 16.40%.

The results indicated that idiopathic scoliosis patients had improved VC, FVC, and MVV 3 months after intervention (16.51%, 16.11%, and 22.16%, respectively) compared to post-intervention (7.19%, 5.72%, and 4.95%, respectively).



VC – vital capacity, FVC – forced vital capacity
MVV – maximal voluntary breathing

Figure 2. Mean values of pre, post, and follow-up of VC, FVC, and MVV in AIS

Discussion

This study included patients with AIS who underwent concave thoracotomy and posterior correction. At 3 months after surgery, patients in the study group showed greater gains in VC, FVC, and MVV compared to pre-op and directly after the intervention. This study is one of the few studies that investigated the effect of concave thoracotomy on chest expansion in AIS patients, and the findings revealed a statistically significant reduction in expansion following surgery.

Our results were supported by the findings of Shi et al. [14], who stated a positive correlation between the postoperative minimized ratio of functional pulmonary parameters and recovery time, with sharp regression in functional pulmonary parameters decreased immediately after the operation, then gradual improvement was obtained. Furthermore,

Table 3. Comparison within the study group for VC, FVC, and MVV

Variable	Items	Mean ± *SD*	Pairwise between the intervention (post hoc)		
			pre vs. post	pre vs. follow up	post vs. follow up
VC	pre	65.00 ± 13.68	65.00 ± 13.68	65.00 ± 13.68	
	post	69.67 ± 13.53	69.67 ± 13.53		69.67 ± 13.53
	follow-up	75.73 ± 11.99		75.73 ± 11.99	75.73 ± 11.99
	MD (change)		4.67	10.73	6.06
	95% CI		–3.58 to 12.91	–2.48 to 18.98	–2.18 to 14.32
	improvement %		7.19%	16.51%	8.70%
	p-value	0.008*	0.513	0.006*	0.228
FVC	pre	62.90 ± 12.94	62.90 ± 12.94	62.90 ± 12.94	
	post	66.50 ± 12.67	66.50 ± 12.67		66.50 ± 12.67
	follow-up	73.03 ± 11.78		73.03 ± 11.78	73.03 ± 11.78
	change (MD)		3.60	10.13	6.53
	95% CI		–4.26 to 11.46	2.27 to 18.00	–1.32 to 14.40
	improvement %		5.72%	16.11%	9.82%
	p-value	0.008*	0.800	0.007*	0.137
MVV	pre	41.83 ± 7.65	41.83 ± 7.65	41.83 ± 7.65	
	post	43.90 ± 7.96	43.90 ± 7.96		43.90 ± 7.96
	follow-up	51.10 ± 8.04		51.10 ± 8.04	51.10 ± 8.04
	change (MD)		2.07	9.27	7.20
	95% CI		–2.90 to 7.04	4.30 to 14.24	2.23 to 12.17
	improvement %		4.95%	22.16%	16.40%
	p-value	0.0001*	0.939	0.0001*	0.002*

VC – vital capacity, FVC – forced vital capacity, MVV – maximal voluntary breathing
MD – mean difference, CI – confidence interval
* significant ($p < 0.05$)

2 years after the surgical intervention, remarkably improved clinical and functional pulmonary parameters compared to initial values were shown not to be statistically different.

Based on published literature, there is a data shortage regarding concave thoracoplasty effectiveness and posterior correction in enhancing pulmonary function and chest expansion.

Kim et al. [15] examined one hundred and eighteen patients with AIS who underwent surgical intervention and stated obvious FVC and FEV1 improvements with dorsal spinal arthrodesis via iliac crest grafting, while no change was seen for dorsal spinal arthrodesis with thoracoplasty when absolute functional pulmonary measures were compared between initial and later follow-ups.

Scoliosis's impact on functional pulmonary parameters is explained by limited volume changes induced by the deformity of dorsal scoliosis. A previous study has shown that dorsal impacts among scoliotic patients were lower during the inspiratory and expiratory phases than in normal controls [16].

A previous clinical trial by Vedantam et al. [10] reported that 3.2 years of follow-up on means of absolute functional pulmonary measurements were improved slightly more than initial measurements among 33 AIS individuals who underwent dorsal thoracoplasty correction. Predicted functional pulmonary outcome improvements follow the same pattern unless they did not recover to initial levels, even if they were extremely close. As well, they revealed improvements in functional pulmonary measurements after two years.

Pulmonary ventilation and associated perfusion functions were evenly distributed between both the convex side and the concave side of the lung. However, the ventilation function variation was substantially less than the variation in AIS perfusion function [17].

While adjusting absolute functional pulmonary outcome measurements to predicted amounts in percentages of both FVC and FEV1, no obvious differences were noted based on gender parameters post-AIS operative correction [18].

The prior observational trial regarding invasive AIS correction via a dorsal approach. Rao et al. [2] found immediate post-operation accelerated recovery in the form of a shorter hospital stay, which can affect the pulmonary system. While compared to initial values, patients treated following pathway implementation had fewer patient-controlled analgesia days, and participants got less opioid pain medication.

After traditional growing rod treatments, predicted improvement gained in FVC and FEV1 was recorded in 71% of AIS populations. Despite, reported FVC and FEV1 improvement, no meaningful changes in predicted gains in FVC and FEV1 were observed. Therefore, no significant changes in overall health, various activities such as ambulating, physical activities, energy/fatigue, and even impact on parents was observed. Pain and emotions were greatly improved, while pulmonary function and everyday functioning were significantly improved [19].

The curve correction rate has steadily increased through the sequential development of numerous correction methods like halo traction after anterior release, dorsal correction plus frontal release, vertebral column resection, and vertebral decancellation and anterior release with internal distraction [17].

In severe cases of AIS, invasive management was advised to regain normal thoracic contour, thus greatly accompanied by recovery of ventilation manoeuvres [4].

Chunguang et al. [20] investigated the outcome of convex short length rib resection using pedicle screws for invasive correction of dorsal AIS. The study demonstrated obvious hump loosening, which modulates dorsal hypokyphosis while minimally compromising functional pulmonary measures. These findings agreed with the current study, which found a lower Cobb angle and improved lung function.

It was revealed that a 5% decrease in FVC post-surgery was considered a postoperative pulmonary function impairment. Further research trials with prolonged follow-up were required to detect how much this decrease in lung function affects daily activities [21].

The current study's findings contradicted those of Duray et al. [22], who found that thoracoplasty in combination with the posteromedial translation technique had no impact on PFT results two years following surgery.

According to the findings of Leong et al. [8] compressed 7th to 10th ribs localized the opposing middle and lower lobes at the concave portion, which addresses as main ventilation components.

Researchers found that invasive management of kyphoscoliosis, gained reduced pulmonary physiological dead space by 40% and no immediate benefits gained by invasive correction on pulmonary regional perfusion in those who had > 65-degree Cobb angles. They attributed this conclusion to a potentially irreversible lung alteration and recommended surgery before the angle of curvature reached 70 degrees [23, 24].

Patients affected by severe scoliosis, typically in case of a > 150-degree primary dorsal Cobb angle, frequently have significantly impaired ventilation, plus thoracic deformity; even when compensating halo-pelvic traction was verified, which massively limits ventilation [12].

Regarding thoracoplasty, the approach includes limited rib excision in comparison with other invasive techniques [25]. Fewer rib excisions consequently have minimal distortion of the chest thus leading to minimizing harmful functional pulmonary consequences.

Surgical AIS correction advances chest wall mechanics, thus facilitating respiratory mechanics of musculature to improve their performance, and the patient is better able to generate increased maximal inspiratory pressure and maximal expiratory pressure [26].

Patients with AIS who engaged in a four-month exercise program that included three weekly sessions of stretching and aerobic activities reported greater increases in respiratory muscle strength than those who did not participate [27]. AIS is characterized by asymmetry and a rise in tone of the erector spinae. Its uneven tone, which occurs on both sides of the spine, promotes destabilization and aberrant development. Understanding this notion may aid in the development of more effective diagnostic and therapeutic procedures for scoliosis [28].

Other researchers had investigated pulmonary regional functioning correlated to Cobb angles in AIS. Their study demonstrated that restricted functioning did not significantly differ between both spinal curvature sides. Also, they concluded difficulty in predicting regional pulmonary functioning depending on the radiographic-defined spinal curvature [6].

The lung tissues are compressed, which leads to early closure of the airway by atelectatic patches, particularly on physically limited portions, thus minimizing optimum VC, also limiting the ordinary flow of expiratory rate [25].

Another clinical trial examined traditional PSF management, they had ensured later functional pulmonary recovery, mainly VC, as well as remarkable 2-year functional pulmonary improvements. The relevance may be a factor due to the small sample size [7].

Many surgical parameters, including fused levels determined by counting the number of levels fused, the correction approach, and the degree in which neither the sagittal nor frontal might be contributing to these conflicting findings.

Limitations

Current study limitations involve a small study population size, thus larger-scale investigations on a larger AIS population are warranted. Also, there were no long-term follow-ups in this trial, which could explain based on dorsal and lower spinal alignments were supposed to alter on extended duration, patients should be monitored for longer periods to determine spontaneous changes in each parameter.

Conclusions

Patients with AIS who had a concave thoracoplasty and posterior correction showed greater gains in Cobb angles and pulmonary function tests, with decreased chest expansion after 3 months of surgical intervention. However, each case of scoliosis necessitates individualized treatment. The current study offers practical value and fills a research need in this area. Future research activities should emphasize elucidating areas of confusion to improve care in the AIS population.

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Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Research Ethics Committee of the Faculty of Physical Therapy at Cairo University (approval No.: P.T.REC/012/003580).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Disclosure statement

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Conflict of interest

The authors state no conflict of interest.

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