Original Article

Comparison of volume controlled ventilation and pressure controlled ventilation in patients undergoing robot-assisted pelvic surgeries: An open-label trial

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ABSTRACT

Background and Aims: Although volume controlled ventilation (VCV) has been the traditional mode of ventilation in robotic surgery, recently pressure controlled ventilation (PCV) has been used more frequently. However, evidence on whether PCV is superior to VCV is still lacking. We intended to compare the effects of VCV and PCV on respiratory mechanics and haemodynamic in patients undergoing robotic surgeries in steep Trendelenburg position. **Methods:** This prospective, randomized trial was conducted on sixty patients between 20 and 70 years belonging to the American Society of Anesthesiologist Physical Status I–II. Patients were randomly assigned to VCV group (n = 30), where VCV mode was maintained through anaesthesia, or the PCV group (n = 30), where ventilation mode was changed to PCV after the establishment of 40° Trendelenburg position and pneumoperitoneum. Respiratory (peak and mean airway pressure [AP_{peak}, AP_{mean}], dynamic lung compliance [C_{dyn}] and arterial blood gas analysis) and haemodynamics variables (heart rate, mean blood pressure [MBP] central venous pressure) were measured at baseline (T_1), post-Trendelenburg position at 60 min (T_2), 120 min (T_3) and after resuming supine position (T_4). **Results:** Demographic profile, haemodynamic variables, oxygen saturation and minute ventilation (MV) were comparable between two groups. Despite similar values of $AP_{mean,}$ AP_{peak} was significantly higher in VCV group at T2 and T3 as compared to PCV group (P < 0.001). C_{dyn} and $PaCO_2$ were also better in PCV group than in VCV group (P < 0.001 and 0.045, respectively). **Conclusion:** PCV should be preferred in robotic pelvic surgeries as it offers lower airway pressures, greater C_{dyn} and a better-preserved ventilation-perfusion matching for the same levels of MV.

Key words: Pneumoperitoneum, pressure controlled ventilation, robotic pelvic surgeries, Trendelenburg, volume controlled ventilation

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INTRODUCTION

In the current era of minimal invasive surgery, robotic technologies provide unprecedented control and precision of surgical instruments. With these technologic innovations, new anaesthetic implications for patient care are being discovered. To facilitate robotic pelvic surgeries, the patient must be placed in steep (40°) Trendelenburg position for several hours. When combined with pneumoperitoneum, it can result in adverse respiratory and haemodynamic consequences such as decreased lung compliance, higher airway

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pressures, hypercarbia, hypotension and increased central venous pressure (CVP).[1,2]

Volume controlled ventilation (VCV) is the conventional mode familiar to most anaesthesiologists in the operating room. In the VCV mode, the ventilator calculates a flow rate based on the set tidal volume (V_T) and the length of inspiratory time to deliver that V_T. VCV can deliver adequate V_T but at the cost of increased airway pressure and possible barotrauma. Pressure controlled ventilation (PCV) is an alternative mode of ventilation. It uses a decelerating flow in which the flow rate reaches the highest possible value at the beginning of inspiration, and diminishes throughout inspiration according to the pressure target. The resulting V_T depends on the pressure limit and the respiratory system compliance and resistance. Furthermore, the limitation of pressure levels has a positive effect on the patient's haemodynamics and might even reduce the risk of barotrauma.[3,4]

Whether PCV is superior to VCV in laparoscopic robotic surgery is still a matter of debate. We hypothesised that PCV ensures lower airway pressures and better-preserved haemodynamics as compared to VCV. In the present study, we aimed to compare effects of VCV and PCV modes on respiratory mechanics and haemodynamics in patients undergoing robot-assisted pelvic surgeries.

METHODS

After getting approval from institute's ethical committee, sixty patients of either sex belonging to the American Society of Anesthesiologist (ASA) physical status I and II, aged between 20 and 70 years, having body mass index (BMI) between 18 and 30 kg/m^2 and scheduled to undergo robotic surgery in steep Trendelenburg position were enrolled. Patients with morbid obesity, history of asthma, chronic obstructive pulmonary disease, restrictive pulmonary disease, cor pulmonale, severe hepatorenal dysfunction and active cardiac conditions were excluded from this study.

All the patients were examined during the pre-operative visit a day before surgery. Routine blood investigations including complete haemogram, renal function test, blood sugar, chest X-ray and electrocardiogram (ECG) were carried out and recorded. Informed and written consent was obtained from all the patients. They were kept nil per orally 8 h before surgery and were pre-medicated with alprazolam 0.5 mg per oral (PO) the night before surgery and ranitidine 150 mg and granisetron 2 mg PO on the morning of the surgery.

In the operation room, ECG, non-invasive blood pressure (BP) and pulse oximeter for peripheral oxygen saturation (SpO_2) were attached and an intravenous (IV) line was secured. A peripherally inserted central venous catheter to measure CVP and an invasive arterial line for continuous BP measurement were secured under local anaesthesia and a baseline arterial blood gas (ABG) analysis was done. The patients were then pre-medicated with IV midazolam 0.03 mg/kg and IV fentanyl 2 μg/kg.

After pre-oxygenation with 100% oxygen for 3 min, induction of anaesthesia was done with IV propofol 2 mg/kg and IV vecuronium 0.1 mg/kg, trachea was secured with an appropriate sized endotracheal tube, and a nasogastric tube was inserted to decompress the stomach. The fraction of inspired oxygen (FiO_2) concentration was kept at 50% with the oxygen-air mixture. Sevoflurane was used as maintenance anaesthetic to keep Bispectral Index (BIS) of 40–50. Neuromuscular blockade and analgesia were maintained with an infusion of vecuronium monitored through a peripheral nerve stimulator to keep post-tetanic counts at 10–12 and infusion of fentanyl 1 μg/kg/h.

The Drager Primus workstation (Dräger Primus®, Lübeck, Germany) which incorporates an electrically driven piston ventilator was used to deliver the anaesthetic gases. All the operations which included radical hysterectomies and prostatectomies were performed with the help of the 'da Vinc' robotic system (da Vinci® Surgical System, Intuitive Surgical, Inc., USA) in the steep Trendelenburg tilt (40° from horizontal).

Initially, patients were ventilated with VCV mode with V_T of 8 ml/kg, inspiratory: expiratory (I: E) of ratio1:2, PEEP of 4 cm H_2O and the respiratory rate (RR) was adjusted so as to maintain an end-tidal CO_2 ($EtCO_2$) pressure of 35–40 mmHg. Baseline (time T_1) parameters such as heart rate (HR), mean BP (MBP), CVP, temperature, SpO_2, $EtCO_2$, V_T, RR, BIS, peak and mean airway pressures (AP_{peak} and AP_{mean} respectively) and dynamic lung compliance (C_{dyn}) were recorded.

After proper positioning, pneumoperitoneum was created with CO_2 to a pressure of 15 mm Hg, and the patients were slowly placed in steep Trendelenburg position. Patients were then randomly allocated using computer generated random numbers to one of the two groups VCV or PCV group.

In the VCV group, the initial ventilator settings were continued throughout the study. In the PCV group, the AP_{peak} was chosen so as to achieve a V_T of 8 ml/kg with the RR adjusted to maintain $EtCO_2$ between 35 and 40 mm Hg. The FiO_2, I:E ratio and the V_T were held constant throughout the study in both groups. At 60 min (time T_2) and 120 min (time T_3) after the establishment of Trendelenburg position and pneumoperitoneum, all the above-mentioned parameters were recorded. At skin closure (time T_4), supine position was resumed, and all the parameters were recorded again in both groups. An ABG analysis was also done at T_4. At the conclusion of surgery, neuromuscular blockade was reversed, and patient extubated when train of four ratio approaches 0.9.

Primary outcome variable was the difference in AP_{peak} levels at T_2 between the two groups. Secondary outcome variables included the effect on haemodynamics, AP_{mean}, C_{dyn}, CVP, oxygenation and $PaCO_2$-$EtCO_2$ gradient.

Statistical analysis

With reference to previous studies, sample size of thirty patients per group was calculated based on a mean difference of four in AP_{peak} at time point T2 between the PCV and VCV, with a population variance of $(4)^2$, a two-sided alpha of 0.05 and a power of 90%.[1] All the data were compiled and analysed statistically using Statistical Package for Social Sciences version 20 (IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp., NY, USA). Descriptive statistics were presented in terms of numbers and percentages for categorical variables and in terms of the mean, standard deviation and/or median for the continuous variables. Two independent group variables were compared using the Student's *t*-test or Mann–Whitney U-test when criteria for normal distribution were met or not met respectively. Continuous data were analysed using independent samples *t*-test except for intragroup analysis which was analysed using paired *t*-test. Categorical data were analysed using Chi-square test. $P < 0.05$ was considered statistically significant.

RESULTS

The study enrolled 82 patients, out of them 22 patients were excluded as 17 subjects were not meeting inclusion criteria and five subjects refused to be a part of the study. Remaining sixty patients were randomised into two groups of thirty patients according to the ventilatory mode used intraoperatively (VCV or PCV) [Figure 1]. Demographic profile (age, sex, BMI and ASA grade), haemodynamic variables (HR and MBP), SpO_2 and minute ventilation (MV) were comparable between two groups [Table 1]. Despite similar values of AP_{mean}, AP_{peak} was significantly high in VCV group at T_2 and T_3 as compared to PCV group ($P < 0.001$) [Figure 2]. In both groups, CVP increased after positioning and pneumoperitoneum but was significantly higher in VCV group ($P < 0.001$ at T_2 and T_3 both) [Figure 3]. Fall in C_{dyn} from the baseline at time point T_2 and T_3 was lower in the PCV group (37.9% and 39.5%, respectively) compared to that in VCV group (54.10% and 54.50%, respectively) ($P < 0.001$ and 0.004 at T_2 and T_3 respectively) [Figure 4]. ABG analysis showed a statistically significant increase in $PaCO_2$ at T_4 time in VCV group (P value 0.045). Rest of the parameters comprising pH, PaO_2, SaO_2 and BE were comparable at time points T_1 and T_4 between both groups. The $PaCO_2$-$EtCO_2$ gradient at the end of surgery

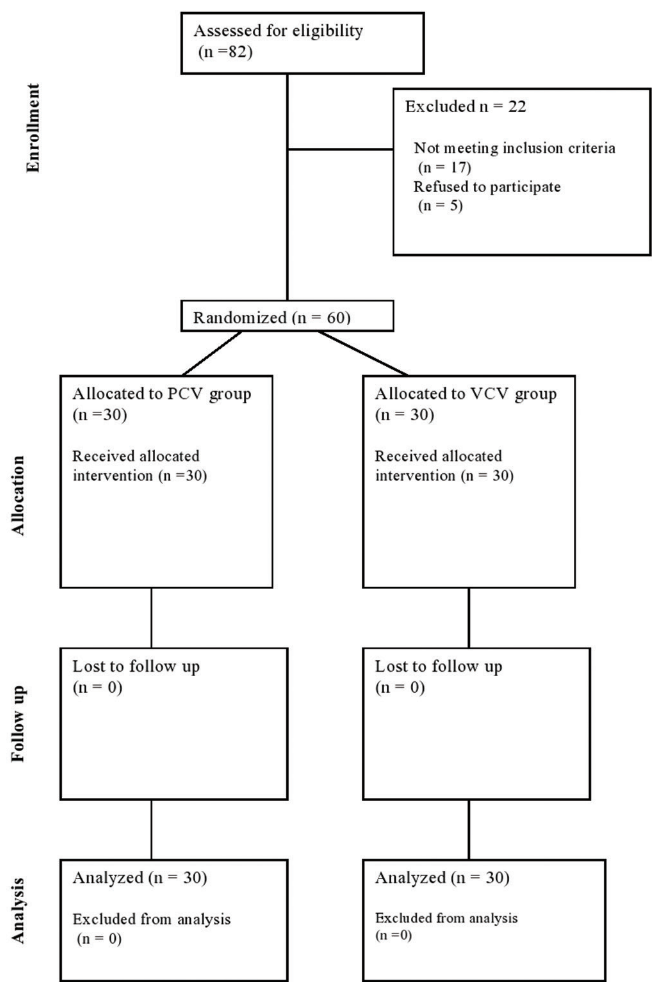

Figure 1: Consort flow chart

Table 1: Demographic data, haemodynamic variable, oxygen saturation and minute ventilation

Variable	Group PCV (*n*=30)	Group VCV (*n*=30)	*P*
Age (years)	54.60±11.35	56.17±11.09	0.591
Gender (male/female)	13/17	19/11	0.121
ASA grade (I/II)	21/09	18/12	0.45
BMI (kg/m²)	25.42±3.19	25.81±2.20	0.581
Heart rate (/min)			
T_1	68.00±11.67	68.23±10.18	0.935
T_2	67.59±10.78	64.47±8.16	0.217
T_3	71.24±10.60	69.60±9.61	0.536
T_4	72.59±11.11	72.37±10.49	0.938
MBP (mmHg)			
T_1	100.54±13.04	101.68±10.54	0.713
T_2	103.30±8.41	104.87±9.30	0.172
T_3	102.44±7.02	105.39±9.78	0.133
T_4	103.62±9.62	106.14±8.28	0.281
SpO2 (%)			
T_1	99.90±0.30	99.90±0.30	1.00
T_2	99.90±0.31	99.77±0.57	0.279
T_3	99.86±0.35	99.77±0.57	0.443
T_4	99.93±0.26	99.87±0.35	0.422
Minute ventilation (ml/min)			
T_1	5747.67±781.67	5679.0±671.74	0.717
T_2	5965.33±964.53	6179.33±805.81	0.355
T_3	6100.0±903.19	6232.83±882.99	0.567
T_4	6271.33±898.51	6419.33±903.04	0.527

Values shown as mean±SD. PCV – Pressure control ventilation; VCV – Volume control ventilation; SD – Standard deviation; ASA – American Society of Anesthesiologist; BMI – Body mass index; MBP – Mean blood pressure; SpO_2 – Oxygen saturation; T_1 – Baseline; T2 and T3 – 60 and 120 min post-pneumoperitoneum and Trendelenburg position respectively; T4 – At skin closure

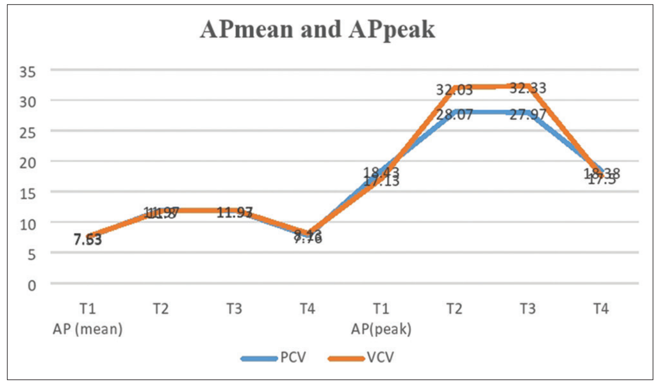

Figure 2: Comparison of AP_{mean} and AP_{peak} between two groups

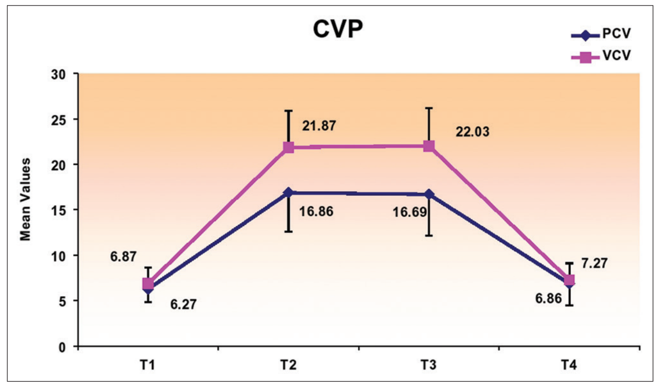

Figure 3: Comparison of central venous pressure between two groups

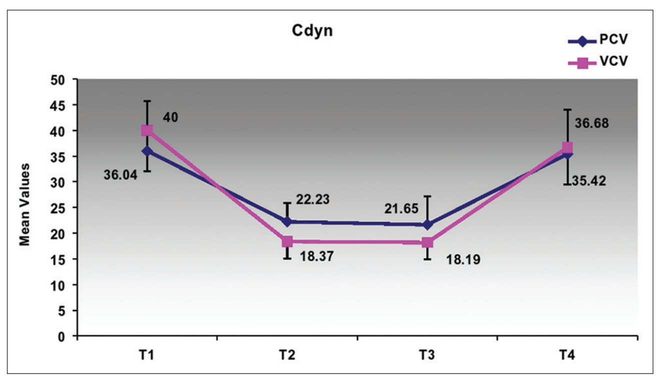

Figure 4: Comparison of C_{dyn} between two groups

was significantly less in PCV group compared to VCV group (P = 0.031) [Table 2].

DISCUSSION

Under anaesthesia, delivery of mechanical ventilation should result in adequate gas exchange with minimum lung injury and lowest possible degree of haemodynamic impairment. Randomised studies and meta-analysis performed to determine optimal ventilatory settings in patients undergoing laparoscopic surgeries suggest PCV to be superior mode as compared to VCV in view of better respiratory mechanics. PCV has also been established ventilator mode for patients with acute lung injury, paediatric patients, patients with bronchopleural fistula and one lung ventilation in view of decreased airway pressure.[5-7] However, the available literature for implementation of ventilatory mode in robotic surgeries in steep Trendelenburg position is limited.

The principle finding of this study is lower AP_{peak} and better C_{dyn} after the institution of pneumoperitoneum and Trendelenburg position for the same V_T in PCV group. Although CVP increased after the institution of pneumoperitoneum and Trendelenburg position in both groups the increase was higher in the VCV group. At the end of surgery, lower mean $PaCO_2$ and better preserved $PaCO_2$-$EtCO_2$ gradient were recorded in the PCV group despite similar values for MV. Both ventilatory modes were found equally efficacious in terms of oxygenation as measured by parameters PaO_2 and SaO_2.

The meta-analysis of eight randomised controlled trials on a comparison of VCV and PCV in laparoscopic

Table 2: Comparison of arterial blood gas variables and arterial-end tidal CO_2 gradient gradient between two groups

variable	Mean±SD		*P*
	PCV (*n*=30)	VCV (*n*=30)	
pH			
T_1	7.42±0.06	7.43±0.04	0.373
T_4	7.34±0.05	7.33±0.06	0.272
PaO_2 (mmHg)			
T_1	189.08±61.81	194.82±45.31	0.683
T_4	197.82±67.69	182.41±47.36	0.314
$PaCO_2$ (mmHg)			
T_1	36.14±4.65	36.65±4.08	0.651
T_4	41.10±7.33	44.72±6.21	0.045
SaO_2 (%)			
T_1	99.07±1.22	99.53±0.49	0.068
T_4	99.32±0.66	99.24±0.71	0.672
HCO_3^- (mEq/L)			
T_1	23.52±2.55	23.69±2.36	0.798
T_4	23.55±2.74	22.56±2.71	0.066
BE			
T_1	(−) 1.06±3.12	0.28±2.55	0.073
T_4	(−) 2.27±3.04	(−) 3.83±2.99	0.052
$PaCO_2$-$EtCO_2$ gradient, median value/IQR			
T_4	7.4/4.17-10.82	11.95/4.52-13.90	0.031

PCV – Pressure control ventilation; VCV – Volume control ventilation; SD – Standard deviation; T_1 – Baseline; T2 and T3 – 60 and 120 min post-pneumoperitoneum and Trendelenburg position respectively; T4 – At skin closure; BE – Base excess; $PaCO_2$-$EtCO_2$ – Arterial-end tidal CO_2 gradient

surgeries by Wang *et al*. suggested that haemodynamic parameters were similar between patients who received PCV and VCV. PCV may associate with better respiratory variables such as lower AP_{peak} and resistance and higher compliance. The observed slight difference in respiratory data between PCV and VCV might be due to different types of surgical procedure. Out of the eight enrolled RCTs, only three included laparoscopic pelvic surgeries which require steep Trendelenburg position that further compromises the respiratory mechanics altered after pneumoperitoneum.[8] Jiang *et al*. also recently conducted a meta-analysis of 27 trials with 1643 cases to compare PCV and VCV modes on different positions (supine, prone and lateral) and conditions (laparoscopic surgery, one lung ventilation, etc.). Their conclusion was better oxygen index and decreased alveolar–arterial oxygen difference (A-aDO_2) with PCV mode. Subgroup analysis revealed that patients having one-lung ventilation or laparoscopic surgery and obese patients benefit significantly from the use of PCV in terms of oxygenation.[9]

Similar findings of lower AP_{peak}, greater C_{dyn}, lower pulmonary arterial and CVP, post-Trendelenburg and pneumoperitoneum with PCV mode of ventilation compared with VCV mode was found in previous studies conducted in robot-assisted laparoscopic radical prostatectomy and laparoscopic gynaecological surgery.[10,11]

Hence, compared with VCV, the association between PCV and a lower AP_{peak} has been a constant finding in various other studies.[12-16] With the initiation of inspiration, flow rates quickly approaches maximum value with a pre-set pressure limitation that is followed by decelerating flow. With this mode, more rapid alveolar inflation is achieved as a result of high initial flow rates because the difference between driving pressure and the alveolar pressure gradient is maximum at the beginning of inspiration.

Since the compliance is inversely related to pressure change (work of breathing), an increase in AP_{peak} will result in fall in lung compliance. With pneumoperitoneum and Trendelenburg position, the diaphragm is elevated, which leads to decreased functional residual capacity and respiratory compliance. In the present study, C_{dyn} decreased in both groups at T_2 and T_3 compared to T_1 (37.9% and 39.5% fall in the PCV group and 54.10% and 54.50% fall in VCV group at T_2 and T_3 respectively), but significantly better preserved in PCV compared to VCV group. It had been demonstrated in studies that with pneumoperitoneum, respiratory system compliance decreased on average by 30%–40%.[17,18] When the 50% decrease in compliance is taken into account, higher compliances achieved with PCV compared with VCV may be important during robotic laparoscopic surgeries performed in steep Trendelenburg position.

By delivering a larger portion of V_T early in the inspiratory phase, the lung is maintained at a higher volume resulting in recruitment of more alveoli. Pressure control ventilation results in a more homogeneous distribution of the V_T in all the ventilated alveoli resulting in better-preserved ventilation-perfusion (V/P) matching and effective removal of CO_2.[19] Thus, the differences in $PaCO_2$ and $PaCO_2$ – $EtCO_2$ gradient between the two groups in our study despite similar values for MV, support the hypothesis of a better V/P matching in the PCV group.

Although CVP increased after the institution of pneumoperitoneum and Trendelenburg position in both groups rise was statistically significant in the VCV group and it returned to baseline comparable range in both groups following reinstitution of supine position after completion of surgery. These findings can be explained by combination of increased intra-abdominal, intrathoracic pressures and acute volume loading during pneumoperitoneum and Trendelenburg position which were less pronounced with PCV group. Significant increase in CVP after the institution of pneumoperitoneum and Trendelenburg position in patients undergoing robot-assisted procedures was seen in many studies, and the rise was more in VCV group in most of the studies.[1,20,21]

The characteristics of PCV, i.e., faster V_T delivery, different gas distribution, and high and decelerating inspiratory flow have been advocated to compensate for any potential reduction in ventilation caused by pressure limitation. Furthermore, the limitation of pressure levels may well have a positive effect on the patient's haemodynamics and might reduce the risk of barotrauma. These benefits of pressure limited approach could be achieved with other pressure targeted mode like Pressure Regulated Volume Control (PRVC) and Adaptive Support Ventilation (ASV), future research in this field is required so that pressure limited approach of ventilation can become the standard of care for patients undergoing laparoscopic surgeries in Trendelenburg position.[22]

A major limitation of our study is that patients enrolled in our study were healthy adults. The presence of obesity, decreased cardiac reserve and underlying pulmonary diseases may alter clinical findings so our results may not be applicable to other populations. As it was an open label trial so observer bias inherent to study design could not be excluded.

CONCLUSION

We conclude that both VCV and PCV provide adequate oxygenation in patients undergoing robotic laparoscopic surgeries in steep Trendelenburg position; however, VCV does so at the expense of increased airway pressures. PCV, which is usually available with modern anaesthesia ventilators, should be preferred over the conventional VCV in these surgeries, as it offers lower airway pressures, greater C_{dyn} and a better-preserved V/P matching for the same levels of MV.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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