Original Article

Sono-anatomical analysis of right internal jugular vein and carotid artery at different levels of positive end-expiratory pressure in anaesthetised paralysed patients

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ABSTRACT

Background and Aims: Increasing the cross-sectional area (CSA) of the internal jugular vein (IJV) improves the success rate of cannulation and decreases complications. Application of positive end-expiratory pressure (PEEP) may increase the CSA of IJV beyond that achieved in Trendelenburg position. However, the optimum PEEP to achieve maximal increase in CSA of IJV and the effect of PEEP on IJV and CA relationship is not known. **Methods:** In this prospective, blinded, randomised controlled study, 120 anesthetised paralysed patients of the American Society of Anesthesiologists physical Status I–II were placed in 20° Trendelenburg position. Patients were randomised into four groups as follows: PEEP of 0, 5, 10 and 15 cmH_2O. CSA, anteroposterior (AP) diameter and transverse diameter (Td) of IJV and overlapping of IJV with CA were assessed using two-dimensional ultrasound. Statistical analysis was performed in SPSS version 21.0 software using Chi-square/Fisher's exact test (categorical data) and analysis of variance (continuous data) tests and $P < 0.05$ was considered statistically significant. **Results:** There was significant increase in AP diameter, CSA and Td with the application of PEEP 10–15 cmH_2O. Increase in CSA up to 25% with PEEP 10 and 44% with PEEP 15 was noted. There was a significant decrease in the overlapping of the internal CA with an increase in PEEP. It ranged from 21% at P0 to 17% P15. **Conclusion:** Application of PEEP 10–15 cmH_2O in Trendelenburg position significantly increased CSA and AP diameter of IJV and decreased CA overlap of IJV in anesthetised paralysed patients.

Key words: Carotid artery, jugular vein, ultrasonography

INTRODUCTION

With landmark-guided internal jugular vein (IJV) cannulation technique, the rate of mechanical complication (pneumothorax, haematoma, line misplacement and haemothorax) is 10%–15% and unsuccessful insertion is up to 20%.[1] Although ultrasound guidance improves the successful insertion rate to 93.9%, first-attempt success rate is only 82% and carotid puncture rate is up to 5.9%.[2]

Ideally, a first-pass technique will minimise risk and maximise success.[3] Increasing the cross-sectional area (CSA) of IJV improves the success rate and decreases complications. Several manoeuvres such as Trendelenburg's position, Valsalva's manoeuvre, hepatic compression and positive end-expiratory

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pressure (PEEP) have been tried to increase the CSA of IJV.[3-5] Application of PEEP of 10–12 cmH_2O in supine position has been found to increase the CSA of right IJV in various studies.[6,7]

In our clinical experience, we observed that addition of PEEP in the Trendelenburg position increases CSA of IJV from its baseline value in Trendelenburg position without PEEP. However, with an increase in CSA of right IJV, carotid artery (CA) overlap area with IJV may alter as both CA and IJV are within the same sheath. Therefore, chances of transjugular CA puncture may increase (transfixation of IJV) with the application of PEEP if CA overlap increases. This may be reduced if the AP diameter of right IJV can be increased or overlap can be decreased. Therefore, it is important to investigate CA overlap simultaneously with the changes in CSA of IJV with the application of PEEP. Studies evaluating this overlap with the application of Valsalva's manoeuvre and high positive airway pressure (PAP) showed conflicting results.[5,8,9]

Therefore, the aim was to investigate the effect of the application of PEEP 5–15 cmH_2O in Trendelenburg position on CA–IJV sonoanatomical relationship by measuring the increase in CSA of IJV.

METHODS

After approval by the Institutional Ethical Committee and obtaining informed written consent, 120 American Society of Anesthesiologists (ASA) I–II patients aged between 18 and 60 years undergoing routine elective surgery were recruited in this prospective, randomised controlled trial between January 2013 and July 2014. Exclusion criteria were ASA Grade III/IV, history of neck surgery, any valvular heart disease, pulmonary artery hypertension, congestive cardiac failure, morbid obesity, severe obstructive pulmonary disease, raised intracranial pressure (ICP), haemodynamically unstable patient, history of previous right IJV cannulation, short neck and haemodynamic instability after application of PEEP.

In the operating room, routine monitoring (oxygen saturation, noninvasive blood pressure, electrocardiography and end-tidal carbon dioxide monitoring) were attached. Anaesthesia was induced with fentanyl 2 mcg/kg, propofol 2–3 mg/kg and vecuronium 0.1 mg/kg or atracurium 0.5 mg/kg. After endotracheal intubation, mechanical ventilation was initiated (Prima SP2, Penlon Inc; Minnetonka, MN, USA). Volume control ventilation with tidal volume 8 ml/kg and rate 10–12 breaths/min was used.

The patients were initially positioned supine without any pillow under the head. The head was turned 30° towards the left side. Ultrasound probe was placed on the right side of the neck at the level of cricoid cartilage near the apex of the triangle formed by the sternal and clavicular head of sternocleidomastoid. The probe was placed perpendicular to the axis of the neck, and a short-axis view of the right IJV and right CA were obtained, and the required measurements were taken. Patients were randomised into four groups. Randomisation was done by computer-generated random number table (www.randomizer.org), and allocation concealment was done using sealed envelope technique.

In Group P0, patients were positioned 20° Trendelenburg with PEEP 0 (control group); in Group P5, patients were positioned 20° Trendelenburg with PEEP 5; in Group P10, patients were positioned 20° Trendelenburg with PEEP 10 and in Group P15, patients were positioned 20° Trendelenburg with PEEP 15.

There were 30 patients in each group. Group P0 served as the control group. The following sonoanatomical measurements were obtained in all the four groups: the CSA of right IJV, the transverse diameter(Td) of right IJV at midline, anteroposterior diameter (APd) and overlapping of right IJV over CA. Overlapping was calculated as transverse diameter of the portion of IJV (cm) overlying the CA and expressed as a percentage using the formula:

Overlapping (%) = (transverse diameter [Td] of the portion of right IJV over carotid in cm/Td of right IJV in cm) × 100.

After positioning and application of PEEP, 2 min time was allowed before measurements were obtained. All the snapshots were taken at the end of expiration by freezing the screen. Measurements were obtained by an independent radiologist from these frozen snapshots who was blinded to the group. The duration of PEEP applied was <10 min. All the ultrasounds were performed by the same experienced anaesthesiologist to have the consistency and probe was held in a way to minimise compression of IJV. All images were obtained using the Sono Site M-Turbo ultrasonography machine (Sonosite Inc., Bothell, WA, USA).

In a previous study by Lee *et al*., increasing PEEP from 0 to 15 cmH_2O increased CSA from 1.30 cm^2 to 2.04 cm^2. Assuming 95% confidence interval, the power of study of 90% and α of 0.05, at least 27 patients were required per group. However, anticipating 10% dropout, 30 patients were included per group.

Statistical analysis was performed using SPSS 21.0 software (IBM Corporations, Chicago). Data were presented as number (%) or mean ± standard deviation/median (range) as appropriate. Supine characteristics among the four groups were compared using the Chi-square/Fisher's exact test (categorical) and analysis of variance (ANOVA) (continuous).

The changes in measured parameters among the four groups were compared using repeated measures and ANOVA.

The Td, AP diameter, CSA and carotid overlapping were compared using ANOVA. Multiple comparisons between individual pairs of groups were done applying the Bonferroni test. A value of $P < 0.05$ was taken to be statistically significant for all data in this study.

RESULTS

One hundred and twenty patients were enrolled in the study. No patients were excluded due to severe hypotension or bradycardia after adding the PEEP [Consort Flow Diagram, Figure 1]. All the demographic parameters were comparable between the groups [Table 1].

Measurement of different IJV parameters and CA overlap in Trendelenburg position before application of PEEP are described in Table 2. All measurements in Trendelenburg position were comparable between the groups.

Changes in the measurement of various parameters in the groups after application of PEEP are described in Tables 3-4.

The percent increase in CSA, Td and APd from PEEP 0–5 is not significant. Application of PEEP 10–15 cmH_2O increased all these parameters as compared to PEEP 0 and compared to previous lower PEEP group as well.

Application of PEEP in Trendelenberg position caused insignificant increase in the CA overlap from its baseline Trendelenberg value in the same group

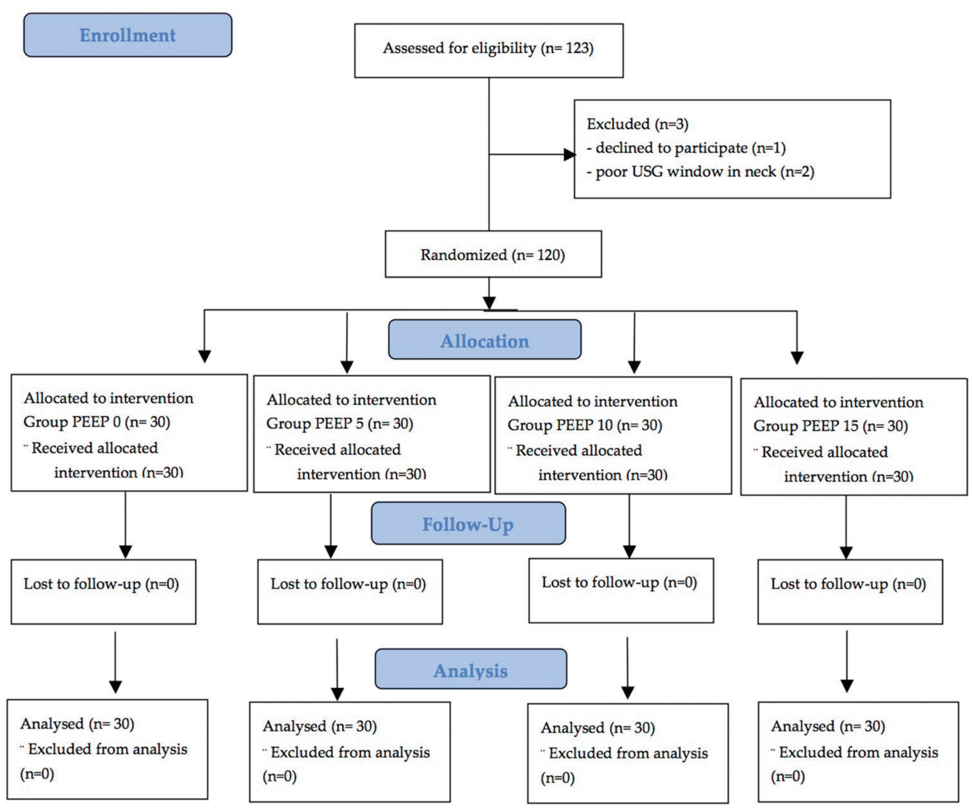

Figure 1: CONSORT flow diagram of patients participating in the study

Table 1: Demographic characteristics					
Parameters	**P0**	**P5**	**P10**	**P15**	**Significance (*P*)**
Age (years)	38.6±11.3	38.3±11.2	39.4±11.4	40.0±11.9	0.933
Sex (male/female; number of patients)	16/14	17/13	12/18	15/15	
Weight (kg)	61.83±6.44	60.13±6.86	62.73±6.19	60.27±6.20	0.405

Table 2: Right internal jugular vein measurements between the groups after Trendelenburg position before application of positive end-expiratory pressure					
Parameters	**P0**	**P5**	**P10**	**P15**	**Significance (*P*)**
Transverse diameter (cm)	1.776	1.790	1.773	1.781	0.794
AP diameter (cm)	0.857	0.882	0.858	0.880	0.346
CSA (cm^2)	1.366	1.405	1.362	1.393	0.523
Carotid overlapping (cm)	0.390	0.353	0.323	0.303	0.079
Percentage of carotid overlapping	21.74	19.76	18.25	17.00	0.087

AP – Anteroposterior; CSA – Cross-sectional area

Table 3: Percentage change in various internal jugular vein parameters in the groups after application of positive end-expiratory pressure from positive end-expiratory pressure 0				
Parameters	**Percentage change**			**Significance (*P*)**
	P0-P5	**P0-P10**	**P0-P15**	
Transverse diameter (cm)	2.8	10.13	15.03	P0 versus P5; *P*=0.221 P0 versus P10; *P*<0.01 P0 versus P15; *P*<0.01
AP diameter (cm)	8.52	15.78	31.68	P0 versus P5; *P*=0.552 P0 versus P10; *P*<0.01 P0 versus P15; *P*<0.01
CSA (cm^2)	9.58	25.70	44.95	P0 versus P5; *P*=0.306 P0 versus P10; *P*<0.01 P0 versus P15; *P*<0.01

AP – Anteroposterior; CSA – Cross-sectional area

Table 4: Right internal jugular vein carotid artery overlap in different groups baseline (Trendelenburg position) and after application of positive end-expiratory pressure					
Variable	**P0 (baseline)**	**P5**	**P10**	**P15**	**Significance (*P*)**
Percentage carotid overlapping baseline and after PEEP	21.74	20.38	18.78	17.67	P0 versus P5; *P*<0.01 P0 versus P10; *P*<0.01 P0 versus P15; *P*<0.01 P0 versus P5; *P*<0.01 P5 versus P10; *P*<0.01 P10 versus P15; *P*<0.01

PEEP – Positive end-expiratory pressure

[Figure 2]. However, with an increase in the amount of PEEP applied, there was a significant and proportional decrease in CA overlap compared to the previous group with smaller PEEP [Table 4].

There were no clinically significant haemodynamic changes with Trendelenburg position and after application of PEEP.

DISCUSSION

In the current study, we found that there is an increase in anteroposterior diameter, Td and CSA of the right internal jugular vein (RIJV) after application of PEEP 10–15 cmH_2O compared to the baseline value of these parameters in Trendelenberg position in anaesthetised paralysed patients. There was decrease in CA overlap after adding PEEP 5–15 cm of H_2O compared to baseline value without PEEP in Trendelenberg position.

The increased CSA may provide a larger target for needle entry. Methods including performing a Valsalva manoeuvre, applying abdominal compression, placing the patient in the Trendelenburg position, increasing positive airway pressure and applying PEEP have been shown to increase the success rate.[3,5,7,10,11]

After application of PEEP 5–15 cmH_2O in Trendelenberg position, we observed a progressive increase in CSA. However, the addition of PEEP 5 cmH_2O did not produce any significant increase in CSA. Therefore, at least PEEP 10 cmH_2O is required to significantly increase CSA of IJV. However, Marcus *et al*. did not find any significant increase in CSA after adding PEEP 5–10 in Trendelenburg position.[3] The difference in the finding can be explained by methodological differences. We allowed 2 min time between application of PEEP and noting the parameters, whereas Marcus *et al*. allowed only 30 s.[3] Addition of PEEP increases intrathoracic pressure and thereby increases CVP and IJV dimension. However, the time required to achieve these changes is not known. Allowing more time perhaps led to better equilibration of pressure transmitted to the venous system in our study. Moreover, Marcus *et al*. infused 500 ml crystalloid before the procedure to increase intravascular volume which could have increased the IJV dimensions in baseline Trendelenberg position itself, minimising further enhancement.[3]

Zhou *et al*. observed an increase in CSA in Trendelenburg position only after application of positive airway pressure above 20 cmH_2O for 30 s, and there was no significant increase in CSA at PAP 15 cmH_2O.[5] However, bradycardia and hypotension were observed at PAP 20–25 cmH_2O. Therefore, application of high positive airway pressure may have adverse consequences and application of PEEP 10–15 cmH_2O should be enough. Moreover, PEEP should be kept applied until the guidewire is inserted as discontinuation of PEEP before guidewire insertion may change the dimension of IJV and thereby causing posterior wall puncture, haematoma and failure to cannulate the vessel.[5] Complete insertion of the guidewire within 30 s may be difficult to achieve and may require more time. Application of PEEP 10–15 cmH_2O for 2 min may, therefore, increase successful IJV cannulation and should not result in bradycardia and hypotension as observed by us.

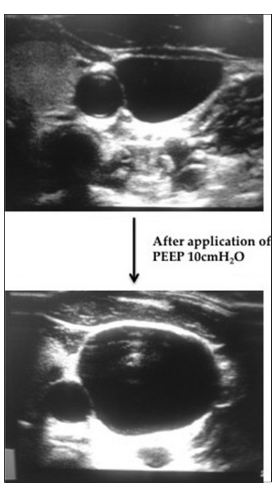

Figure 2: Image showing carotid artery internal jugular vein overlap before and after application of positive end-expiratory pressure

The incidence of CA injury during IJV cannulation under real-time visualisation is 5.9%.[2] This complication can be decreased by decreasing overlap of CA and IJV. A study by Suzuki *et al*. found that application of the Valsalva manoeuvre decreases the overlapping with the common CA.[8] Kitagawa *et al*. similarly found a decrease in percent overlap between IJV and CA after the valsalva manoeuvre (mean value 22.4% vs. 15.2% $P < 0.05$).[9] However, Zhou *et al*. found that CA overlapping with IJV increased with PAP from 15 to 25 cmH_2O.[5] We found that with the application of PEEP 5–15 cmH_2O, CA overlap decreases in each group. To the best of our knowledge, this is the first study which investigated overlapping of the IJV over CA at different levels of PEEP in anesthetised paralysed patients. Although this was an interesting observation, our study was not adequately powered to comment on this. The decrease in overlapping may be due to medial displacement of CA by distension of IJV with the application of PEEP. In addition, IJV diameter increased more in anteroposterior direction than in transverse direction (15% vs. 10% in P10; 31% vs. 15% in P15). A greater increase in AP diameter may reduce posterior wall puncture of IJV, transjugular CA puncture and can reduce overlap of CA by causing medial displacement of CA. The overall incidence of unrecognised puncture of the posterior vessel wall during ultrasound-guided venous cannulation of a phantom performed by emergency medicine residents and attending physicians is 34%.[12] Small IJV and anterior venous wall tenting lead to posterior venous wall penetration and may cause critical arterial injuries in spite of ultrasound guidance.[13] As observed in our study, application of PEEP can increase venous pressure and thereby reduce collapsibility of IJV. The decrease in collapsibility and increase in AP diameter may reduce IJV anterior wall indentation and unrecognised puncture of the posterior vessel wall. Hollenbeck *et al*. and Lee *et al*. similarly observed an increase in AP diameter with the application of PEEP.[6,7]

Other manoeuvres such as Valsalva maneuver and abdominal compression are known to increase the CSA. However, Valsalva manoeuvre requires an assistant for application in mechanically ventilated patients,[8] and may not be advisable in chronic obstructive pulmonary disease (COPD) patients and hypovolaemic patients. Moreover, prolonged use of Valsalva >30 s is not possible, and on the other hand, there may be a risk of the posterior wall of the IJV and ICA puncture, if Valsalva manoeuvre released before guidewire insertion. Applying abdominal compression has a limitation in blunt abdominal trauma patients and patients with abdominal pathologies.

Lobato *et al*. found that a 10° Trendelenburg position increased the RIJV CSA by 25% and a 20° Trendelenburg position increased it by 32% in anaesthetised adults.[10] Clenaghan *et al*. in their study reported that a 25° Trendelenburg tilt achieved the optimum distension, whereas greater angles were not only impractical in unstable patients but also potentially detrimental.[14] Therefore, we applied 20° Trendelenburg position and observed 15% increase in CSA compared to the CSA in the supine position.

We used 30° head rotation in all the patients. A study by Sulek *et al*. found that with increasing head rotation, CA overlap increases and they recommended head rotation <40°.[15]

We have excluded patients with a history of neck surgery, morbid obesity, history of previous right IJV cannulation and short neck to avoid measurement bias. IJV CSA may be altered in valvular heart disease, pulmonary artery hypertension and congestive cardiac failure because of volume and pressure changes, and these patients were excluded from the study. We excluded COPD patients as the application of PEEP may potentially increase air trapping and chances of pneumothorax in COPD patients. Patients with raised ICP were also excluded as increased PEEP may increase ICP in these patients. In haemodynamically unstable patients, application of PEEP may increase the chances of hypotension and bradycardia and therefore, these patients were excluded from the study. Application of PEEP, by increasing CSA and decreasing CA overlap, may also increase the success of landmark-guided RIJV cannulation, where availability of the ultrasonography is limited. Moreover, it may increase first-pass success rate of venous access, when guided by the ultrasound.[5]

The study is not without limitations. We observed only change in CSA and CA overlap and did not perform IJV cannulation. Hence, whether application of PEEP 10–15 cmH_2O for 2 min translates into more successful cannulation and less CA puncture remains to be investigated. Moreover, our study was not adequately powered to detect any side effects (e.g. haemodynamic disturbances) of high PEEP applied in the study. We could investigate the effect of different levels of PEEP in the same patient by sequential application of progressively higher PEEP. However, in this way, subjecting one patient to each subsequent level of PEEP will make the patient under the influence of high PEEP for prolonged period. This may result in PEEP-induced haemodynamic disturbances and raise ethical concerns as there is no other clinical indication of applying PEEP in these patients. We measured CSA of IJV at the end of expiration without considering changes in CSA during the respiratory cycle. It is known that IJV CSA may be affected by respiratory cycle.[6] However, this may be a theoretical concern as it is not possible to cannulate during any specific period of the respiratory cycle. Moreover, the observation that CA–IJV overlap decreased with application of PEEP was an interesting finding; however, the study was inadequately powered to detect any such difference.

CONCLUSION

We conclude that application of PEEP 10–15 cmH_2O in Trendelenburg position increases CSA and AP diameter of IJV and simultaneously decreases CA overlap of IJV in anaesthetised paralysed patients.

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Conflicts of interest
There are no conflicts of interest.

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