Inferior Vena Cava Collapsibility Index versus Central Venous Catheter for Early Detection of Hypovolemia in abdominal Trauma

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ABSTRACT

Background: Abdominal trauma has been considered as a significant cause of morbidity and mortality, necessitating prompt and accurate assessment of fluid status and hypovolemia. The inferior vena cava (IVC) collapsibility index and central venous catheter (CVC) have emerged as potential tools for fluid assessment in trauma patients.

Objective: This study aimed to evaluate the utility of the IVC collapsibility index (IVC-CI) in assessing fluid status and hypovolemia in patients with abdominal trauma.

Patients and Methods: A cross-sectional study that is conducted on 67 trauma patients attended to the Emergency Department (ED) with hypovolemia state to compare IVC-CI with central venous pressure (CVP) as early indicator of hypovolemia in abdominal trauma patients. The diameter of the IVC, the central venous pressure, and the IVC-CI were recorded before and after fluid resuscitation. **Results:** IVC-CI has decreased from base line to follow up after fluid from 54.55 ± 15.23 to 45.06 ± 13.81. IVC-CI has negative association with central venous pressure at base line (P<0.001). IVC-CI has a negative association with urine output (UOP) at baseline (P<0.001). IVC-CI has negative association with central venous pressure and urine output at follow-up (P<0.001). **Conclusion:** IVC-CI had a strong statistically significant inverse association with central venous pressure. IVC-CI was found to be more predictive of fluid responsiveness and early hypovolemic state when compared to central venous pressure. So, the study supported the use of the IVC-CI and CVC as reliable markers for assessing fluid status and hypovolemia in abdominal trauma patients.

Keywords: IVC-CI, CVC, Hypovolemia, Abdominal trauma.

INTRODUCTION

When patients present to the ED with hypovolemia (CVP less than 8 cm H_2O), measuring their CVP is an invasive haemodynamic assessment and a helpful guide for an initial resuscitative response with the goal of reducing morbidity and mortality rates. On the other hand, invasive hemodynamic monitoring can have unfavorable effects when used for CVP monitoring in the ED (arterial puncture, infection, venous thrombosis, and so on), as well as time and practical limitations, such as the need for specialized monitoring equipment and accompanying resources [1].

A central venous catheter shouldn't be used if the patient has certain conditions, such as bleeding or infection at the insertion site. Infections, accidental artery puncture, hematoma, hemothorax, pneumothorax, air embolism, and arrhythmias are all possible complications of a central venous catheter [2]. Because of its safety, non-invasiveness, speed, and convenience as a bedside test, ultrasound has gained popularity in the emergency room. One of the most frequently performed emergency medical examinations, bedside ultrasonography is not a routine radiological investigation but rather is performed to assess a targeted medical issue [3]. Deoxygenated blood is transported to the right atrium of the heart via the IVC. The IVC is a large vein whose dimensions and shape are related to the CVP and blood volume [4].

The internal thoracic artery (IVA) diameter (IVCD) changes size throughout the breathing cycle. When the thorax experiences negative pressure, the IVC narrows as blood is drained into the right atrium. Divide the expiratory IVCD by the inspiration IVCD to get the IVC-CI [5]. The intravascular collapsibility index (IVC-CI) is a non-invasive approach of estimating intravascular volume that is gaining in popularity. Hemodynamic evaluation is best performed with point-of-care ultrasound due to its non-invasiveness, low charge, ease of repeatability, increased availability, and portability [6].

The potential value of the IVC-CI as a non- invasive technique for intravascular volume evaluation is growing. Because of its non-invasive nature, cheap cost, easy repeatability, improved availability, and portability, point-of-care ultrasound is the hemodynamic evaluation modality of choice [7]. The IVC diameter (IVCD) alterations are mainly based on the respiratory stage. Throughout inspiration, the negative pressure is developed in the thorax, causing the IVC to drain into the right atrium, with subsequent reduction in its diameter (IVCD) [8].

This work aimed to assess the utility of the IVC collapsibility index in assessing fluid status and hypovolemia in patients with abdominal trauma.

PATIENT AND METHODS

This cross-sectional observational study was done over a period of one year from May 2022 to May 2023 on trauma patients attended to the Emergency Hospital, Mansoura University. They were presented by clinical signs and symptoms suggestive of hypovolemia (systolic blood pressure below 90 mmHg, heart rate (HR) over 100 beat/minutes, and capillary refill more than 2 seconds).

Inclusion criteria: Patients with age from 18 to 60 years old, from both genders, with accessible central venous

Received: 25/09/2023
Accepted: 23/11/2023

catheter, with abdominal trauma with suspicion of hypovolemic state, and spontaneous breathing patients.

Exclusion criteria: patients with age below 18 or above 60 years, pregnant females, patients with pericardial effusion (PE) with mechanical ventilation (MV) and with malfunctioning central venous catheter.

Methods: The history was taken [allergy, medication currently used, past illness or pregnancy (for females), last meal, events related to injury], frequent reassessment of vitals, head to toe physical examination. Every patient was subjected to advanced trauma life support (ATLS) if needed and it included management of air way if patient was unconscious by opening the mouth by jaw thrust with stability of cervical spines, oropharyngeal and nasopharyngeal airway. Management of breathing was done by high flow nasal canula or mask oxygen and intubation if needed. Management of circulation was done by inserting two wide bore cannulas then administration of 500 ml of normal saline and cross matching blood. Disability was assessed by Glasgow coma score, and pupil examination (size and reaction to light).

Laboratory investigations included complete blood count, arterial blood gases, blood grouping, cross matching, serum creatinine, liver function tests, kidney function tests and INR (International normalized ratio). Radiological investigations included X-ray that was performed on chest, cervical spines, lumbosacral spines, pelvis and imaging of suspected area of injury by Non-contrast CT or X-ray. FAST, rapid bedside US examination conducted by emergency clinicians, and radiologists as a screening test for PE or haemoperitoneum following traumas.

Intravascular volume status evaluation

It was conducted by bedside US to assess the IVCDs, end-inspiratory (IVCi) and end-expiratory (IVCe) measured by 2D bedside US by M-mode in the sub-xiphoid area *(LOGIC P7 pro device, South Korea*) using abdominal or echo probes. Connectors: 1 regular, 2 extras; Transducer: 2.5-10 MHz. The scanning angle of curved array transducers was between 67 and 120 degrees, and the depth was between 21.6 and 248 mm. The patient's supine IVC diameter was measured. The IVC was checked while running the probe under the sternum. Maximum and minimum diameters were taken at random times throughout a natural breathing cycle. The walls of the IVC were visible when we focused on a region no more than 3 cm from the junction of the right atrium. IVCD measured on inspiration and expiration to detect the IVC-CI. The IVC-CIs were measured before fluid administration and after one-liter normal saline intra venous administration. Insertion and evaluation of CVP was done by emergency doctors before and after fluid administration by bedside ruler. The IVC-CI was recorded to be compared to the CVP values. Urinary catheter was inserted, and urine output was calculated before the challenge of one-liter saline and after.

Ethical approval: Approval to conduct this study was obtained from managers of the healthcare facilities where the study was conducted. A written signed consent was taken from parents who agreed to participate in the study before the data collection starts and after approval of the Institutional Research Board in Mansoura University. Also, parents were informed that they can withdraw from the study at any time. The Helsinki Declaration was followed throughout the study's conduct.

Statistical Analysis: Data analysis was analysed by SPSS software, version 25.0. Qualitative data were defined using number and percent. Quantitative data were defined by utilizing median for nonnormal distribution of data and mean±SD for normal distribution of data. The Spearman's correlation was utilized to detect the strength and direction of a linear relationship between two nonnormally distributed variables. ROC curve was utilized to measure validity of continuous variables. Predictive values and accuracy were assessed using cross tabulation. In terms of all the previous tests, p vales were considered significant when its values were less than 0.05.

RESULTS

The present study was cross-sectional study that was conducted on 67 trauma patients attended to the Emergency Department with hypovolemia state to compare IVC-CI with CVP as early indicator of hypovolemia in abdominal trauma patients. Table **(1)** showed that the mean age of the studied cases was 47.48 ± 10.69 years ranging from 23 to 63 years, 59.7% of the studied cases were females and mean body mass index was 29.12 ± 5.29 Kg/m^2 ranging from 21.5 to 40.5 Kg/m^2. 56.7% of the studied cases had penetrating trauma, 32.8% had blunt trauma, 10.4% were fallen from height, 68.7% of the studied cases had diabetes, 53.7% had hypertension and 64.2% were smokers and 55.2% of the studied case died.

Table (1): Demographic characteristics, mode of trauma, mortality and medical history among the studied cases

		n=67	**%**
Age/ years	mean±SD (Min-max)	47.48±10.69 (23.0-63.0)	
Sex	Male Female	27 40	40.3 59.7
BMI (Kg/m^2)	mean±SD(Min-max)	29.12±5.29 (21.5-40.5)	
Mode of trauma	FFH Blunt trauma Penetrating trauma	7 22 38	10.5 32.8 56.7
Mortality	Alive Dead	30 37	44.8 55.2
DM		46	68.7
Hypertension		36	53.7
Smoking		43	64.2

Table **(2)** showed that the mean IVC CI illustrated statistically significant decrease from baseline and before fluid (p<0.001), between baseline and after fluid (p<0.001), which indicated good resuscitation. Mean CVP illustrated statistically significant increase from baseline and before fluid (p<0.001), between baseline and after fluid (p<0.001). Urinary output demonstrated statistically significant increase from baseline and before fluid (p<0.001), between baseline and after fluid (p=0.012). Mean heart rate illustrated statistically significant decrease from baseline and before fluid (p=0.002) and between baseline and after fluid (p=0.003). Mean systolic blood pressure demonstrated no statistically significant change from baseline and before fluid (p=0.182) and between baseline and after fluid (p=0.741). Mean diastolic blood pressure demonstrated no statistically significant change from baseline and before fluid (p=0.122) and between baseline and after fluid (p=0.102).

Table (2): Values of IVCCI, CVP, UOP, DBP and SBP at baseline before and after fluid.

		Mean±SD Median (Min-max)	Test of significance
IVC CI	Baseline	54.55±15.23 52(12-98)	p1=0.06 p2<0.001* p3<0.001*
	Before fluid	54.09±14.31 52(11-92)	
	After fluid	42.06±13.81 40(10-88)	
CVP (cmH_2o)	Baseline	3.31±1.44 2.89(0-8.99)	p1=0.107 p2<0.001* p3<0.001*
	Before fluid	3.32±1.46 2.89(10-8.8)	
	After fluid	6.45±2.08 4.08(1.08-10)	
UOP (ml)	Baseline	245.34±77.46 249(150-460)	p1=0.321 p2<0.001* p3=0.012*
	Before fluid	247.58±75.58 257(158-360)	
	After fluid	306.48±77.87 290(175-510)	
Heart rate (Beat/minute)	Baseline	105.12±29.66 103(70-119)	p1=0.159 p2=0.0002* p3=0.003*
	Before fluid	104.81±30.26 101(70-119)	
	After fluid	82.89±21.07 82(58-102)	
Systolic blood pressure (mmHg)	Baseline	92.07±27.35 91(75-110)	p1=0.182 p2=0.673 p3=0.741
	Before fluid	92.21±25.29 93(75-110)	
	After fluid	100.63±28.42 99(75-118)	
Diastolic blood pressure (mmHg)	Baseline	52.73±17.08 50(39-70)	p1=0.121 p2=0.065 p3=0.102
	Before fluid	53.07±16.28 51(39-70)	
	After fluid	59.24±18.17 58(40-98)	

p1: significance between baseline and before fluid administration, p2: difference between baseline and after fluid, p3: difference between before and after fluid administration.

Table **(3)** showed that there was statistically significant positive association between CVP and and(r=0.719). There was no significant association detected between CVP and systolic blood pressure at base line or before or after fluid (r=0.291) and diastolic blood pressure after fluid (r=0.314). A statistically significant negative association between CVP and the following: heart rate at baseline (r=-0.284), heart rate before fluid (r=-0.279) and heart rate after fluid (r=-0.616). The table also showed a statistically significant negative association between IVC-CI and the following: CVP at base line and before and after fluid. Significant negative association between IVC-CI and UOP at base line and before and after fluid. Significant positive association between IVC-CI and heart rate at base line and before and after fluid. There was no significant association between IVC-CI and systolic blood pressure at base line and before and after fluid (r=0.619). There was no significant association between IVC-CI and diastolic blood pressure at base line, before and after fluid (r=0.583).

Table (3): Association between CVP and IVC-CI as regard data collections

		CVP		IVC CI	
		r	p value	r	p value
UOP	Baseline	0.700	0.001*	-0.881	<0.001
	before fluid	0.675	0.001*	-0.064	<0.001
	after fluid	0.719	0.001*	-0.805	<0.001
Heart rate	Baseline	-0.284	0.02*	0.203	0.001
	before fluid	-0.279	0.02*	0.150	0.001
	after fluid	-0.616	0.001*	0.976	0.001
Systolic blood pressure	Baseline	0.072	0.565	-0.064	0.608
	before fluid	0.091	0.464	-0.065	0.599
	after fluid	**0.291**	**0.017***	**_0.146**	**<0.21***
Diastolic blood pressure	Baseline	0.062	0.620	-0.08	0.534
	before fluid	0.029	0.818	-0.149	0.229
	after fluid	**0.314**	**0.01***	**-0.123**	**<0.314***

Table **(4)** demonstrated that CVP at baseline and at follow up was good (0.766 & 0.743) with the best detected cut off point for baseline was 2.065 yielding sensitivity (Sn) of 78.4%, specificity (Sp) of 63.3% and total accuracy was 71.6%. The best detected cut off point for CVP at follow up was 4.04 yielding Sn of 70.3%, Sp 70.0% and total accuracy is 70.1%.

Table (4): Validity of CVP at baseline, IVC at follow up as regards hypovolemia and fluid responsiveness

	AUC (95% CI)	**P value**	**Cut off point**	**Sensitivity %**	**Specificity %**	**PPV%**	**NPV%**	**Accuracy %**
CVP baseline	0.766 (0.648-0.884)	0.001*	2.065	78.4	63.3	72.5	70.4	71.6
CVP follow up	0.743 (0.622-0.865)	0.001*	4.04	70.3	70.0	74.300	65.6	70.1

Table **(5)** demonstrated that IVC at baseline and at follow up was excellent (0.910 & 0.894) with the best detected cut off point for baseline was 55 % yielding Sn of 89.2%, Sp of 84.6% and the total accuracy was 85.1% and the best detected cut off point for IVC CI at follow up was 60.5 % yielding Sn of 83.8%, Sp 83.3% and the total accuracy was 83.6%.

Table (5): Validity of IVC at baseline, IVC at follow up as regards hypovolemia and fluid responsiveness

	AUC (95% CI)	**P value**	**Cut off point**	**Sensitivity %**	**Specificity %**	**PPV%**	**NPV%**	**Accuracy %**
IVC baseline	0.910 (0.841-0.980)	<0.001*	55	89.2	80.0	84.6	85.7	85.1
IVC after one liter saline (0.9) days	0.894 (0.817-0.971)	<0.001*	60.5	83.8	83.3	86.1	80.6	83.6

DISCUSSION

This cross-sectional study was conducted on 67 trauma patients who attended to the Emergency Department with hypovolemia state aiming to compare IVC-CI with CVP as early indicator of hypovolemia among cases with abdominal traumas. Assessment of haemodynamics could be accomplished through invasive approaches, which included invasive arterial blood pressure (ABP) and invasive CVP through CVC inserted in jugular vein but their reliability were decreased owing to its invasive nature and associated adverse events [9]. In addition, non-invasive approaches were used and included non-invasive ABP and HR monitoring which are of great sensitivity without risks of adverse events**.** IVC-CI is considered as an indirect approach to evaluate CVP by utilizing US for assessment of intravascular fluid condition [10].

The results of this study reported that the mean age of the studied cases was 47.48 ± 10.69 years ranging from 23 to 63 years, 59.7% of the studied cases were females, mean body mass index was 29.12 ± 5.29 Kg/m^2 ranging from 21.5 to 40.5 Kg/m^2. A statistically significant increase in urinary output (ml per hour) from 245.34 ± 77.46 at baseline and 247.58 ± 75.58 before fluid to 306.48 ± 77.87 at last follow up after fluid. **Arnous *et al.*** [11] reported also that the mean UOP in the 1st day was 461.4, in a gradual manner elevated in the 2nd and in the 3rd day to 711.1 with a statistically significant decrease in heart rate (beat per minute) from 105.12 ± 29.66 at baseline to 82.89 ± 11.07 at last follows up. Also, the study demonstrated a statistically significant positive association between IVC CI and HR at last follow up (r=0.976). Likewise, **Arnous *et al.*** [11] recorded that the mean HR was 112.31 with the range of 90-131 b/m in the 1st day, it diminished in a gradual manner in the 2nd day and more in the 3rd day to 91.2 b/m with the range of 75-110 b/m, they reported that there was significant positive association between IVC-CI and HR on the corresponding point of time; r=0.72, 0.47, and 0.47 in the 1st, 2nd, and 3rd day correspondingly.

Results demonstrated statistically significant decrease in IVC CI (%) from baseline 54.55 ± 15.23 and 54.09 ± 14.31 before fluid to after fluid 42.06 ± 23.81. A statistically significant increase in CVP (mmH_2O) from 3.31 ± 1.44 at baseline and 3.32 ± 1.46 before fluid to 6.45 ± 2.08 at last follow up after fluid. As regards, between IVC-CI at baseline and CVP, among studied cases, this study revealed that there was statistically significant negative association between IVCCI and CVP at baseline (r=-0.730)**.** Negative association between IVCCI and urine output at baseline (r=-0.881). Moreover, there was statistically significant negative association between IVC CI and CVP at Last follow up (r=-0.625) and IVC CI and UOP at Last follow up (r=-0.805). Supporting the same results, **Ilyas *et al.*** [12] reported that there was a negative association between CVP and IVC-CI, that was statistically significant (p<0.0005). **Arnous *et al.*** [11] Agree with our findings, and stated that the mean CVP in the 1st day was 4.4 mmH_2O, then it steadily elevated in the 2nd and more in 3rd day to 9.4 mmH_2O. Also, **Elbaih and Housseini** [13] reported that CVP showed a significant association with IVC-CI (P≤0.001). They displayed a negative association between CVP and IVC-CI. Similarly, **Stawicki *et al.*** [14] studied the behavior of CVP across relevant IVC-CI ranges and estimated the effect of PEEP on the CVP and IVC-CI relationship. They observed a negative association between CVP and IVC-CI and observed that every 1 mmHg increase in CVP matches with a mean change of 3.3% in IV-CI. The statistical results reinforced the belief that minor collapsibility is associated with hypervolemia or normovolemia and increased collapsibility is associated with intravascular fluid drop. They discovered a significant association between CVP and sonographic IVC measurements in spontaneously breathing cases. In addition, **Abdelwahab and El-Wahab** [15] displayed a significant association between IVC measurements and CVP among cases with spontaneous breathing and mechanically ventilated cases (p < 0.001). **Shalaby *et al.*** [16] demonstrated a significant negative association between IVC-CI and CVP measurement. Also, **Garg *et al.*** [17] assessed the efficacy of ultrasonographic measured IVC-CI in correlation with CVP in cases with septic shock, requiring MV. They reported that for fluid resuscitation, CVP and IVC CI are inversely correlated and US could be helped as an efficient modality to detect fluid resuscitation. **Wiryana *et al.*** [18] found that the median CVP, the median of maximum IVCD, and the median of IVC-CI were 11 cmH_2O, 1.67 mm and 29.6% correspondingly. They revealed a strong significant negative association between CVP and IVC-CI (p<0.001). In addition, **Orso *et al.*** [19] have demonstrated that US assessment of IVCD as well as its respiratory variations doesn't appear to be a consistent approach for prediction of fluid response.

The current study proved that as regarding fluid responsiveness, IVCCI at baseline had sensitivity of 89.2% and specificity of 80% with cutoff of 55 (P value <0,001). Also, IVCCI had sensitivity of 83.8% and specificity of 83.3% at follow up. While, central venous pressure had sensitivity of 78.4% and specificity of 63.3% at baseline and sensitivity of 70.3% and specificity of 70% at follow up with area under curve of 0.766 and 0.743 contagiously (P <0.001). **Unal Akoglu and Akoglu** [20] revealed that respiratory change in IVCD has limited ability for prediction of fluid responsiveness, especially among cases with spontaneous ventilation on MV. By using IVC US to aid in therapeutic decisions, the clinical context must be considered. In such analysis, seventeen researches were comprised. It has been demonstrated that the Sn and Sp of IVC-US as an indicator for fluid responsiveness were 0.6 and 0.7 correspondingly. **Elbaih and Housseini** [13] discovered that IVCCI demonstrates 100% Sp and Sn in prediction of fluid responsiveness when ≥ 50%. In addition, they demonstrated that bedside US assessment of IVC-CI could be a helpful bedside approach for EC specialists. The specialist could have the ability to get a

bedside assessment of intravascular volume by the IVC-CI evaluation throughout normal respiration. Bedside US of the IVC, in association with traditionally used markers, could be a helpful adjunct in the assessment of EC cases. **Azzam [21]** assessed the association of IVCDs and CVP in cases with circulatory collapse and confirmed that IVC-CI could be sued as a sensitive and safe substitution for CVP in terms of evaluating fluid condition in such critically ill cases.

CONCLUSION

There was a significant reduction in IVC-CI, decrease in HR, significant increase in urine output and significant increase in CVP after fluid resuscitation. IVC-CI had a strong statistically significant inverse association with CVP. This study supported the use of the IVC-CI and CVC as reliable markers for assessing fluid status and hypovolemia in abdominal trauma patients. When compared to CVP, the IVC-CI was found to be more predictive of fluid responsiveness and early hypovolemic state.

- **Conflict of interest**: None.
- **Sources of funding**: Nil.

REFERENCES

1. **Mielke D, Wittig A, Teichgräber U (2020):** Peripherally inserted central venous catheter (PICC) in outpatient and inpatient oncological treatment. Support Care Cancer, 28 (10): 4753-4760.
2. **Arlati S (2023):** Monitoring and Interpretation of Vital Signs. In: The High-Risk Surgical Patients. Aseni P, Massimiliano A, Ari Leppäniemi G, Chiara O (edit.), Springer, Pp: 41-63. https://link.springer.com/book/10.1007/978-3-031-17273-1
3. **Polyzogopoulou E, Velliou M, Verras C *et al.* (2023)**: Point-of-Care Ultrasound: A Multimodal Tool for the Management of Sepsis in the Emergency Department. Medicina (Kaunas), 59 (6): 1180. doi: 10.3390/medicina59061180..
4. **Ruge M, Marhefka G (2022)**: IVC measurement for the noninvasive evaluation of central venous pressure. J Echocardiogr., 20 (3): 133-143.
5. **La Via L, Astuto M, Dezio V *et al.* (2022)**: Agreement between subcostal and transhepatic longitudinal imaging of the inferior vena cava for the evaluation of fluid responsiveness: A systematic review. J Crit Care, 71: 154108.
6. **Bentzer P, Griesdale D, Boyd J *et al.* (2016):** Will This Hemodynamically Unstable Patient Respond to a Bolus of Intravenous Fluids? JAMA., 316: 1298–1309.
7. **Stawicki S, Braslow B, Panebianco N *et al.* (2009)**: Intensivist use of hand-carried ultrasonography to measure IVC collapsibility in estimating intravascular volume status: associations with CVP. J Am Coll Surg., 209 (1): 55-61.
8. **Lyon M, Verma N (2010)**: Ultrasound guided volume assessment using inferior vena cava diameter. The Open Emergency Medicine Journal, 3 (1): 22-24.
9. **Marik P, Cavallazzi R (2013)**: Does the central venous pressure predict fluid responsiveness? An updated meta-analysis and a plea for some common sense. Crit Care Med., 41 (7): 1774-1781.
10. **Murthi S, Fatima S, Menne A *et al.* (2017)**: Ultrasound assessment of volume responsiveness in critically ill surgical patients: Two measurements are better than one. J Trauma Acute Care Surg., 82 (3): 505-511.
11. **Arnous A, Omar M, Dorgham E *et al.* (2022)**: Inferior Vena Cava Collapsibility Index versus Central Venous Pressure for Assessment of Intravascular Volume Status in Injured Traumatized Patients. The Egyptian Journal of Hospital Medicine, 87 (1): 1752-1757.
12. **Ilyas A, Ishtiaq W, Assad S *et al.* (2017)**: Association of IVC diameter and collapsibility index with central venous pressure in the assessment of intravascular volume in critically ill patients. Cureus, 9 (2): e1025. doi: 10.7759/cureus.1025.
13. **Elbaih A, Housseini A (2018)**: Validity of Shock Index, Modified Shock Index, Central Venous Pressure and Inferior Vena Cava Collapsibility Index in Evaluation of Intravascular Volume among Hypovolemic Egyptians Patients. American Journal of Diagnostic Imaging, 4 (1): 5. DOI:10.5455/ajdi.20180318114502
14. **Stawicki S, Kent A, Patil P *et al.* (2015)**: Dynamic behavior of venous collapsibility and central venous pressure during standardized crystalloid bolus: A prospective, observational, pilot study. International Journal of Critical Illness and Injury Science, 5 (2): 80-84.
15. **Abdelwahab H, El-Wahab R (2017)**: Association of bedside ultrasonographic measurement of IVC diameter and caval index with CVP in spontaneously breathing and mechanically ventilated patients. J Emerg Med Critical Care, 3 (1): 2-6.
16. **Shalaby M, Roshdy H, Elmahdy W *et al.* (2018)**: Association between central venous pressure and the diameter of inferior vena cava by using ultrasonography for the assessment of the fluid status in intensive care unit patients. The Egyptian Journal of Hospital Medicine, 72 (10): 5375-5384.
17. **Garg M, Sen J, Goyal S *et al.* (2016)**: Comparative evaluation of central venous pressure and sonographic inferior vena cava variability in assessing fluid responsiveness in septic shock. Indian Journal of Critical Care Medicine, 20 (12): 708-12.
18. **Wiryana M, Sinardja I, Aryabiantara I *et al.* (2017)**: Central venous pressure correlates with inferior vena cava collapsibility index in patients treated in intensive care unit. Bali Journal of Anesthesiology, 1 (1): 7-9.
19. **Orso D, Paoli I, Piani T *et al.* (2020)**: Accuracy of Ultrasonographic Measurements of Inferior Vena Cava to Determine Fluid Responsiveness: A Systematic Review and Meta-Analysis. J Intensive Care Med., 35 (4): 354-363.
20. **Unal Akoglu E, Akoglu H (2023)**: Does respiratory variation in inferior vena cava diameter predict fluid responsiveness in adult patients? A systematic review and meta-analysis of diagnostic accuracy studies. Hong Kong Journal of Emergency Medicine, 30 (5): 291-304.
21. **Azzam R (2021)**: The Role of Ultrasound Guided IVC-CI versus Central Venous Pressure in Assessment of Critically Ill Patients. The Medical Journal of Cairo University, 89: 597-602.