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Klinik Çalışma

Inferior vena cava diameter as a marker of early hemorrhagic shock: a comparative study

Erken hemorajik şokun bir belirleyicisi olarak inferior vena kava çapı: Karşılaştırmalı bir çalışma

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BACKGROUND

We determined the value of the inferior vena cava (IVC) diameter for predicting acute blood loss in control and blunt trauma patients and compared this with other parameters of hemorrhagic shock.

METHODS

Fifty volunteers and 28 consecutive hemorrhagic shock patients were recruited prospectively to participate in the study. Vital signs, blood lactate, and serum bicarbonate were measured, and shock index and base excess were calculated. Anteroposterior (AP) and mediolateral (ML) IVC diameters during inspiration and expiration were measured in the right subcostal region. IVC diameters in hemorrhagic shock patients were compared with those of controls and were also compared with other hemorrhagic shock parameters.

RESULTS

A significant relationship was determined between mean IVC AP and ML diameters during expiration and inspiration on admission in the study group and in the control group (p=0.000, p=0.000, p=0.000, p=0.000). Serum lactate levels correlated significantly with all IVC diameters (r=55), especially the IVC ML diameter during expiration.

CONCLUSION

IVC diameter, as measured by transabdominal ultrasound, was more accurate than the shock index and other commonly used non-invasive predictors of acute blood loss (blood pressure, heart rate per minute, serum lactate level, base deficit).

Key Words: Base deficit; hemorrhagic shock; inferior vena cava; lactate; shock index; ultrasound.

AMAÇ

Sağlıklı bireylerde ve künt travma hastalarında akut kan kaybının tahmininde inferior vena kava (İVC) çapının değeri saptandı, hemorajik şokun diğer parametreleri ile karşılaştırıldı.

GEREÇ VE YÖNTEM

Elli gönüllü ve 28 ardışık hemorajik şok hastası çalışmaya alındı. Hayati bulgular, kan laktatı ve serum bikarbonatı ölçüldü, şok indeksi ve baz fazlası hesaplandı. İVC'nin Antero-posterior (AP) ve mediyolateral (ML) çapları sağ subkostal bölgede inspirasyon ve ekspirasyon sırasında ölçüldü. Hemerajik şok hastalarındaki İVC çapları ve diğer hemorajik şok parametreleri kontrol grubununkilerle karşılaştırıldı.

BULGULAR

Kabulde çalışma grubu ile kontrol grubunun inspirasyon ve ekspirasyon sırasındaki ortalama AP, ML ve İVC çapları arasında anlamlı ilişki saptandı (p=0,000, p=0,000, p=0,000, p=0,000). Serum laktat seviyeleri bütün İVC çapları ile özellikle exspirasyon sırasındaki İVC ML çapı ile anlamlı korele idi (r=55).

SONUÇ

Hemorajik şok hastalarında transabdominal ultrasonografiyle ölçülen İVC çapı; şok indeksi ve akut kan kaybının tahmininde yaygın olarak kullanılan kan basıncı, dakikadaki nabız sayısı, serum laktat seviyesi ve baz açığı gibi diğer non-invaziv prediktörlerinden daha doğru bir prediktördür.

Anahtar Sözcükler: Baz açığı; hemorajik şok; inferior vena cava; laktat; şok indeksi; ultrason.

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Despite advancements in the treatment of trauma patients, uncontrollable hemorrhage remains an important factor in 30-40% of trauma-related deaths.[1-3] These deaths usually occur within the first six hours and are often preventable. Early detection of hypovolemia and prediction of deterioration may be helpful to prevent at least some of these deaths. In the emergency department (ED), initial physical examination findings, hemoglobin levels, and hematocrit values are not sufficient in the detection of hemorrhagic shock.[4-7]

Biochemical markers such as arterial lactate and base deficit have been used as surrogate markers for significant hemorrhagic shock, both of which are sensitive indicators of hypoperfusion.[8-11] Ultrasound (US) is a fast and non-invasive tool that can demonstrate pericardial, pleural and peritoneal fluid during the initial evaluation of the trauma patient.[12] Although computerized tomography (CT) and diagnostic peritoneal lavage (DPL) are more sensitive than US in many situations, they are time-consuming and invasive.[13,14] In this study, we investigated the accuracy of the inferior vena cava (IVC) diameter measured with transabdominal US to determine the presence of hemorrhagic shock in ED patients, and we compared the efficiency of this measurement with that of other parameters of acute blood loss: serum lactate, base excess, blood pressure, heart rate per minute and shock index.

MATERIALS AND METHODS

Patients and Data Collection

The study protocol was approved by the Board of Ethics of Meram Faculty of Medicine, Selcuk University. Cases who were in the early stage of hemorrhagic shock and had mild level of shock findings according to the classification of the American College of Surgeons were included prospectively in the study. Between October 2005 and June 2007, patients over 18 years old admitted to our tertiary care university hospital ED with trauma, gastrointestinal bleeding, and hemoptysis, with a shock index (pulse rate / systolic blood pressure) above 0.7, were approached for inclusion into the study in a consecutive fashion. If the patient was unable to grant consent for medical reasons, relatives of the patient were approached to obtain informed consent. Patients with a history of cor pulmonale, tricuspid valve regurgitation, congestive heart failure, renal failure, portal hypertension, and those taking antihypertensives or inotropic agents were excluded. Data from trauma patients with an eventual diagnosis of cardiac tamponade and/or pneumothorax were excluded from analysis. The control group consisted of healthy individuals selected by convenience sampling from among hospital personnel and relatives of patients who volunteered for the study.

Heart rate and arterial blood pressure were measured by the same healthcare personnel in all study patients, and the shock index was calculated. In the trauma patients, duration of prehospital care, amount of prehospital fluid given, cause of blood loss, examination findings, and hourly urine output were recorded. The general assessment of the cases was performed with Glasgow Coma Score (GCS) since it was planned to include not only the cases with hemorrhagic shock secondary to trauma but also those with hemorrhagic shock caused by massive hemoptysis, massive hematuria and gastrointestinal system bleeding.

Laboratory tests included hemoglobin, hematocrit, arterial blood gas, base deficit, lactate, and serum electrolytes.

The primary outcome measure was survival at 24 hours. Those who survived were further divided into groups as those who received non-surgical or surgical treatment.

Secondary outcome measure was the survival of the cases in the first 10 days in their clinics after receiving treatment.

Ultrasonographic Measurements

IVC diameters of patients were measured separately by two certified ED specialists with trauma radiology training with a Philips 98041 model US606096 US machine (Philips Medical, Bothell, USA) using a 3.5 Hz curvilinear probe. The mean of these two measurements was obtained.

While the patients were supine, with the probe angled towards the right shoulder from the subcostal area, a cross-sectional view of the IVC was obtained of the entrance of the hepatic veins into the IVC. Maximum and minimum values of anteroposterior (AP) and mediolateral (ML) diameter measurements were taken during both inspiration and expiration (Fig. 1).

Statistical Methods

SPSS for Windows® version 15 (SPSS Inc., Chicago, USA) package software was used in the statistical analysis of the data. In intergroup comparisons, Student t-test was used in cases when parametric conditions were met, and Mann-Whitney U test was used when these conditions were not met. In addition, chi-square test was used in categorized data. The relationships between parameters were assessed using Pearson correlation test. A value of $p<0.05$ was accepted as significant.

RESULTS

During the study period, 28 patients with blunt thorax and/or abdominal and/or pelvic and/or extremity trauma and patients with gastrointestinal bleeding (15 male, mean age: 36±15 years) gave informed consent to participate in the study; routine parameters were

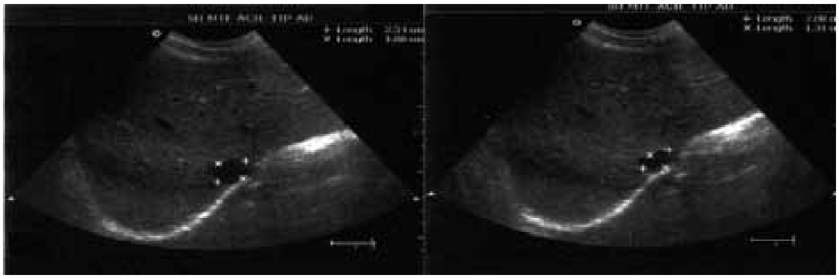

Fig. 1. Axial cross-section ultrasound of the inferior vena cava during expiration and inspiration showing measurements.

measured and IVC diameters were determined by US. Seventeen cases, who were included initially since they had gastrointestinal bleeding, massive hemoptysis and hemorrhagic shock caused by massive hematuria (most of which were caused by overdose warfarin), were excluded from the study due to the presence of other accompanying diseases. Similarly, 23 cases who were included initially with hemorrhagic shock secondary to trauma were excluded since they had serious shock findings and accompanying diseases and were in the pediatric age group.

During the same time period, a convenience sample of 50 control subjects (22 males, 28 females, mean age: 36±11 years) was selected among the patients' relatives and hospital employees. Differences between the groups regarding gender and age were not statistically significant (p=0.4 and p=0.6, respectively).

Mechanisms of injury/illness in the study patients were as follows: motor vehicle accident in 19, fall from a height in five, stabbing in one, and gastrointestinal bleeding in three. Of the 19 motor vehicle accident patients, 10 had orthopedic injuries, seven had more than one focus of bleeding, seven had thoracic injuries, six had an amputated extremity, six had solid organ injury, four had intraabdominal hemorrhage, two had retroperitoneal bleeding, and one had significant bleeding from a scalp laceration. The sources of bleeding in the thorax and abdominopelvic region were determined by ultrasonography (USG). The source of bleeding could not be determined by USG in one patient.

Blood pressure was below 90 mmHg in eight of the 28 study patients. Three patients initially had a normal heart rate (<100 beats/min): one who died in the emergency department due to traumatic amputation of both lower extremities, and two who were admitted to surgery for intraabdominal hemorrhage. On the other hand, three patients with normal arterial blood pressure were administered medical treatment. The bleeding source could not be determined by USG in one patient in the patient group. A retroperitoneal hematoma was determined on CT in this patient. Although this patient was hypotensive (70/30 mmHg) and tachycardic (117/min, shock index of 1.7), his IVC diameters were higher than in the control group.

Fourteen patients were treated surgically and 14 were treated medically. Seven of the medically treated patients died within 24 hours. All the exitus cases had trauma. Most of them had serious thoracal and central nervous system traumatic damage.

One of those treated surgically died of multiorgan failure on day 10.

Vital signs, shock index and USG measurements of the patients and control subjects are given in Table 1 and Fig. 2. No significant correlation was found between any IVC diameter and heart rate, systolic blood pressure, diastolic blood pressure, shock index, prehospital duration, urine output, hemoglobin, hematocrit, leukocyte count, or base excess. Lactate level correlated strongly with IVC diameters and most strongly with the ML IVC diameter during expiration (Table 2).

In the control group, IVC diameter did not correlate with shock index (Table 3).

Bicarbonate, base excess, diastolic blood pressure,

Table 1. Vital signs, shock index (heart rate / systolic blood pressure) and inferior vena cava (IVC) diameters (mm, mean±SD) and p values in the study and control group patients

	Study group	Control group	p
Systolic blood pressure (mmHg)	79±18	121±14	0.000
Diastolic blood pressure (mmHg)	44±22	75±9	0.000
Heart rate (beats/minute)	128±19	79±12	0.000
Shock index (beats/SBP mmHg)	1.7±0.6	0.6±0.1	0.000

AP: Anteroposterior; ML: Mediolateral; SBP: Systolic blood pressure.

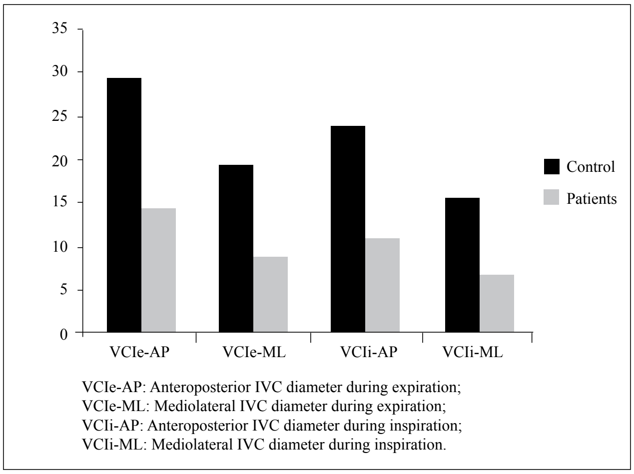

Fig. 2. Inferior vena cava (IVC) diameters (left axis, in mm) as measured with a transabdominal 3.5 MHz ultrasound probe during expiration and inspiration in trauma and control patients.

and ML IVC diameters during expiration and inspiration were significantly lower in patients who died within 24 hours, whereas lactate was significantly higher than in those who did not die within 24 hours. Bicarbonate and base excess values were significantly higher (p=0.042, p=0.013, respectively) in surgically-treated patients, whereas lactate values were significantly lower (p=0.04). However, there was no difference between these two groups regarding any of the IVC measurements, shock index or vital sign parameters (all p>0.05).

Inferior vena cava measurements of the control subjects with a shock index >0.7 were not significantly different from those of control subjects with a shock index ≤0.7 (p>0.05).

DISCUSSION

Hemorrhagic shock is caused by rapid blood loss, most commonly from traumatic injuries or gastrointestinal bleeding.[14,15] Blood pressure is not a reliable indicator of the amount of hemorrhage unless blood loss is extensive.[16] The basal heart rate of a particular patient is unknown when the patient is admitted to the ED.[17] Although tachycardia is a symptom of acute blood loss, it may not be sensitive or specific enough to diagnose or monitor hemorrhagic shock, as heart rate can vary widely according to different internal and external stimuli.[18]

The normal shock index, defined as heart rate divided by systolic blood pressure, ranges from 0.5 and 0.72 in adults.[19] An increase in shock index occurs with progressive loss in circulation blood volume (CBV), and a shock index >1 is an indicator of blood loss and high mortality.[19,20] Birkhahn et al.[17] believed that a high shock index was clinically more useful in acute hemorrhage than changes in blood pressure, heart rate, and other parameters. In our study, shock index did not correlate with pH, lactate, base excess, HCO_3, urine output, hemoglobin, or any of the IVC diameters. A large proportion (32%) of our control subjects had a shock index >0.7, making this a non-specific indicator of significant hemodynamic abnormality. In other studies, shock index was high in a variety of shock states with normal and elevated levels of serum lactate.[21] The fact that there was no significant difference in IVC diameters in those with high and normal shock indices in our study suggests that IVC diameter may provide more reliable hemodynamic information than the shock index.

The diameter of the IVC varies with total body fluid status and respiration, with its diameter decreasing

Table 2. The correlations and p values between VCI diameters and other shock parameters (shock index, systolic blood pressure, diastolic blood pressure, heart rate, HCO_3, base excess, lactate, and Htc) in the shock group.

		Shock index	SBP	DBP	HR	HCO_3	BEe	Lactate	Hct
VCIeAP	Pearson Correlation	-.296	.167	.017	-.425*	.458*	.431*	-.540**	-.129
	P Values	.126	.396	.932	.024	.014	.022	.004	.513
	n	28	28	28	28	28	28	26	28
VCIeML	Pearson Correlation	-.204	.411*	.212	-.071	.510**	.495**	-.552**	-.153
	P Values	.298	.030	.278	.721	.006	.007	.003	.436
	n	28	28	28	28	28	28	26	28
VCIiAP	Pearson Correlation	-.153	.135	-.032	-.296	.388*	.388*	-.549**	-.108
	P Values	.437	.493	.870	.126	.042	.041	.004	.583
	n	28	28	28	28	28	28	26	28
VCIiML	Pearson Correlation	-.006	.237	.162	.052	.448*	.411*	-.463*	.021
	P Values	.975	.225	.411	.793	.017	.030	.017	.917
	n	28	28	28	28	28	28	26	28

*Correlation is significant at the 0.05 level; **Correlation is significant at the 0.01 level.
VCIe-AP: Anteroposterior IVC diameter during expiration; VCIe-ML: Mediolateral IVC diameter during expiration;
VCIi-AP: Anteroposterior IVC diameter during inspiration; VCIi-ML: Mediolateral IVC diameter during inspiration; SBP: Systolic blood pressure;
DBP: Diastolic blood pressure; HR: Heart rate. BEe: Base excess during expiration.

Table 3. The correlations and p values between VCI diameters and shock index, systolic blood pressure, diastolic blood pressure, and pulse rate in the control group

		Shock index	Systolic BP	Diastolic BP	Pulse rate
VCIe-AP	Pearson Correlation	-.082	.158	.232	.038
	P values	.570	.272	.105	.795
	n	50	50	50	50
VCIe-ML	Pearson Correlation	-.138	-.120	.029	-.230
	P values	.340	.407	.841	.108
	n	50	50	50	50
VCIi-AP	Pearson Correlation	-.148	.042	.147	-.117
	P values	.305	.773	.307	.420
	n	50	50	50	50
VCIi-ML	Pearson Correlation	-.253	-.118	.024	-.239
	P values	.077	.416	.867	.056
	n	50	50	50	50

* Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level.
VCIe-AP: Anteroposterior IVC diameter during expiration; VCIe-ML: Mediolateral IVC diameter during expiration;
VCIi-AP: Anteroposterior IVC diameter during inspiration; VCIi-ML: Mediolateral IVC diameter during inspiration.

during inspiration.[14] IVC diameter has been studied in the evaluation of volume status in heart failure and dialysis patients. After ultrafiltration, IVC diameter, CBV, and body weights of dialysis patients decrease.[22] These changes in the IVC diameter are more prominent during expiration than inspiration.[23] In another study, IVC diameter during expiration was more valuable than atrial natriuretic peptide (ANP) and brain natriuretic peptide (BNP) to determine CBV.[24] IVC diameter during expiration and ANP correlate highly with blood volume during ultrafiltration.[25] IVC diameter can accurately reflect central venous pressure[26] and can be used to monitor the response to fluid therapy.[27-29]

In light of the above studies, measurement of IVC diameter may be a reasonable initial procedure to detect rapid, hemodynamically significant hemorrhage. Lyon et al.[14] found a significant difference between IVC diameters during inspiration and expiration in 31 healthy blood donors before and after giving blood. They maintained that IVC diameter was an accurate sign of blood loss, and should be incorporated into the focused abdominal sonography of trauma (FAST) US exam. Limitations of the above study were its performance in healthy individuals, and its lack of comparison with other commonly used parameters of hemorrhagic shock.

In Yanagawa et al.'s[30] prospective study, IVC diameter in the shock group (n=10) trauma patients (no fluid replacement treatment pre-hospitalization and systolic blood pressure <90 mmHg) was measured during expiration. The IVC diameter increased significantly, according to the comparison of admission values and those obtained after five days of treatment. In that study, the cases with trauma exhibiting no signs of hemorrhagic shock and with blood pressure over 90 mmHg were included in the control group (n=25), and only AP IVC diameter in expiration was evaluated. The AP IVC diameter of the cases in the shock group was significantly lower than in the control group at admission. However, some of the cases in the shock group with normal blood pressure and heart rate but low AP IVC diameter in expiration at admission had the symptoms of shock requiring blood transfusion during the follow-up period. They concluded that IVC diameter was a valuable marker for the early diagnosis of hypovolemia in trauma patients. In the studies mentioned above, the IVC diameter was measured on a longitudinal axis view, but we felt that the transverse image was more reliable for measuring AP and ML diameters during inspiration and expiration.

In contrast to the study by Yanagawa et al.,[30] we compared IVC diameters with a variety of other markers of hemodynamic status, as well as with survival within 24 hours. Although we did not measure IVC diameters in a serial fashion as is usual, we included normotensive as well as hypotensive patients with acute hemorrhage. Diastolic blood pressure and ML IVC diameter were the best measures to discriminate between survivors and non-survivors.

Study Limitations

The shock index was >1.0 in all of our study patients. Inclusion of patients with a shock index between 0.7 and 0.9 would provide a larger patient sample for testing the robustness of our findings.

In conclusion, USG measurement of the IVC diameter is a non-invasive technique that can be used as a part of the FAST exam to assess the hemodynamic and volume status of critical patients with hemorrhagic shock and their response to treatment. A small ML IVC diameter portends a high mortality in these patients. The IVC diameter in this setting is more valuable than other traditional shock parameters, such as lactic acid, base excess and shock index.

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